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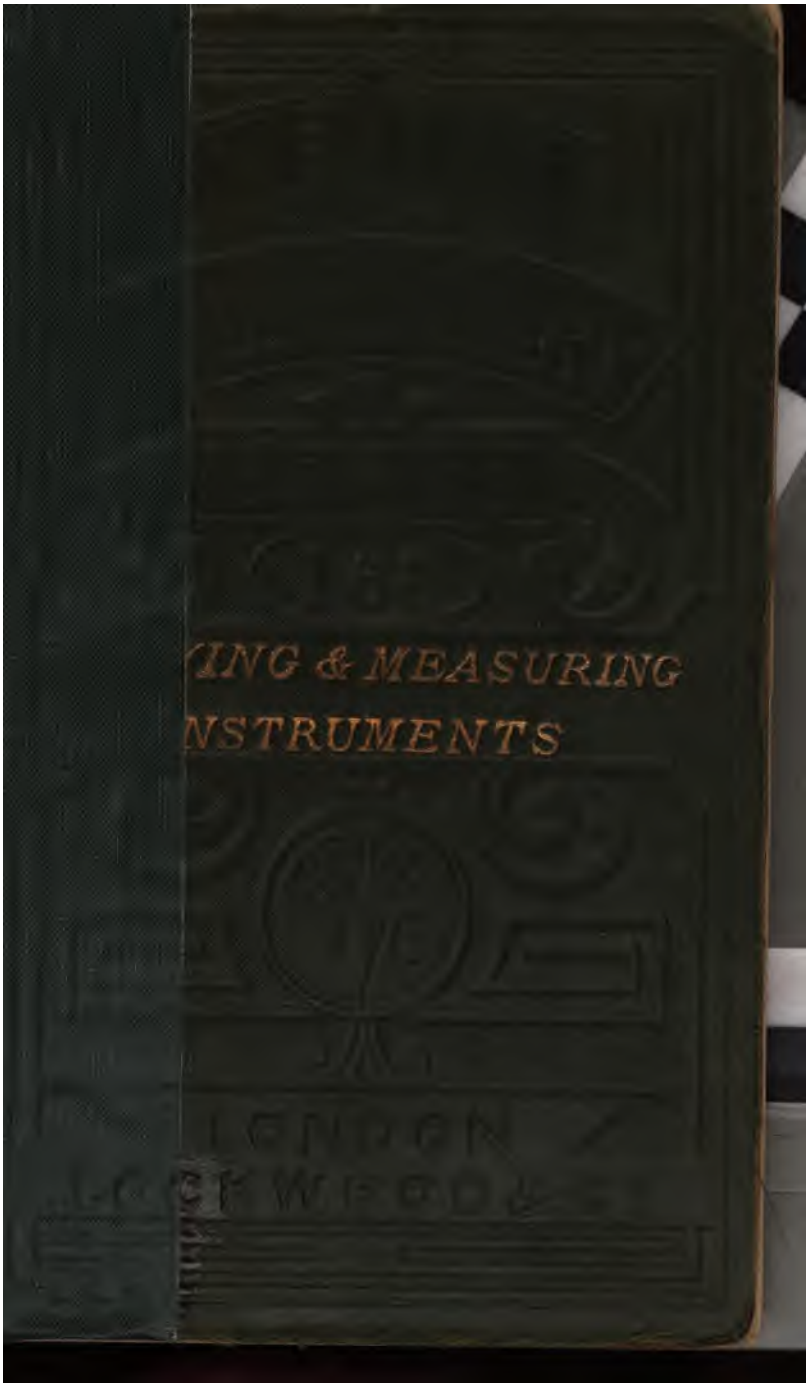
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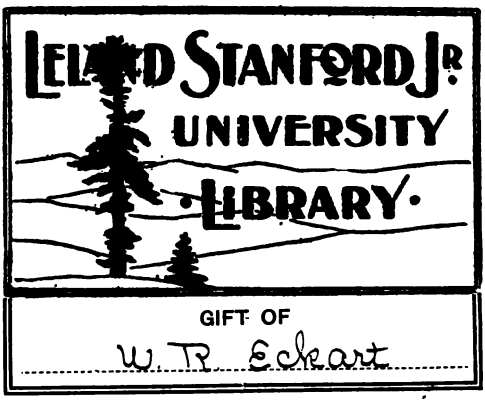

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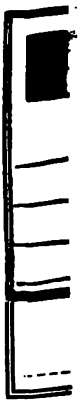

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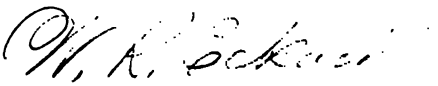

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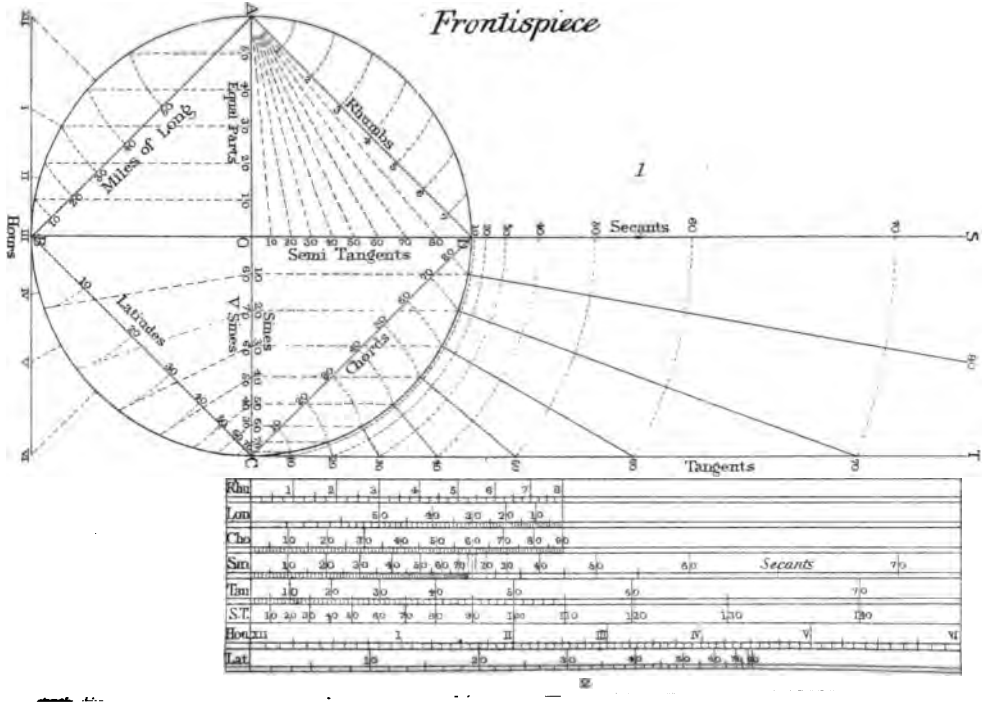

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BY

J. F. HEATHER, M.A.,

LATE OF THE ROYAL MILITARY ACADEMY, WOOLWICH; AUTHOR OF "PRACTICAL PLANE GEOMETRY," "DESCRIPTIVE GEOMETRY," ETC., ETC.

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THIS popular treatise on the "Construction, Adjustment, Testing, and Use of Mathematical Instruments" appeared originally in 1849, and has since been used continuously in Government military and naval schools; and forms, by authority, part of a midshipman's kit. In presenting it for the tenth time to the public it has been entirely re-written, and full development given to the description, with their most recent improvements, of such mathematical instruments as come within the classes mentioned on either of its title-pages. This has necessitated the division of the subjects into three distinct portions, the second volume being devoted to Optical Instruments, and the third to Surveying and Astronomical Instruments.* To meet, however, the convenience of those schools which have introduced the original work as a text-book, the NINTH EDITION has been stereotyped, and copies of that edition will continue to be supplied as long as the heads of such establishments may require them.

* Mathematical Instruments Part III., Optical Instruments, by J. F. H. Mathematical Instruments: Parts IV. and V., Surveying and Astronomical Instruments, by J. F. H.

PREFACE TO VOL. I.

Upon the publication of the original edition of this treatise the author was very greatly and very agreeably surprised by the large number of complimentary letters that he received from persons engaged in a variety of pursuits, many of whom were entirely unknown to him. The praises, thus liberally bestowed on his humble work, were supplemented by its introduction, as a text-book, into numerous educational establishments, and its selection by the Admiralty to form part of a midshipman's kit.

It was manifest, then, that his little book had supplied a want that was strongly felt; and the writer, fully aware of its deficiencies, has long been anxious for the opportunity to improve upon his first essay, which has been afforded him by the liberality of the present proprietors of the Weale Series.

The subjects of Optical Instruments, and of Surveying and Astronomical Instruments, having been removed, to be treated of more fully in separate volumes, sufficient space has been obtained in this volume for a considerable development of that portion of the work, entitled Part I., allotted to the description of Drawing Instruments; while in Part II., now devoted to the consideration of Instruments for Measuring, and for the mechanical performance of arithmetical computations, the principle of the slide-rule has been, it is hoped, clearly explained, the comparative merits of different modes of construction have been discussed, and plain and simple rules for the numeration of the results obtained have been given.

The want of a method of so using the slide-rule, that it should of itself indicate the numeration of the results ob-

tained, and thus become its own interpreter, has been so serious a drawback on its value as a mechanical calculator, that the small extent to which it has hitherto come into general use is not to be wondered at. Not only has no such method been heretofore published, but the accomplishment of so desirable an object has been deemed impracticable. Thus the eminent writer* of the article on the slide-rule in Knight's "English Encyclopædia" remarks:—"Attempts are made in works professing to explain the slide-rule to give rules for the denomination of the character of the figures in the answer, but without any success. It is all very well for a few chosen examples, but an attempt to do without the book soon shows the insufficiency of rules. If on a large scale 653 should be the figures of an answer, common sense applied to the problem must say whether it is ·0653, ·653, 6·53, 65·3, 653, 6530, 65300, &c., which is meant."

The principal obstacle to the discovery of the very simple rules for numeration on the A and B lines, laid down in the text (p. 102), appears to have arisen from the unnecessary repetition of the line of numbers, from 1 to 10, upon *both* these lines.

At all events, the Author was led to the discovery of these rules by the examination of the rule designed by Mr. S. Coulson, supplied to him by the manufacturers, Messrs. Dring and Fage, on which the line of numbers, from 1 to 10, is laid down on the A line *once only* in the entire length of the rule, while it is laid down on the B line *twice*, on the slide, formed in two pieces, numbered on from one to the other. This rule, being used so that the results sought shall be found on the B line, or slide, the correct denomination of its figures is determined by the section of the slide upon which it appears.

To apply, then, the same method of numeration to the ordinary form of the rule, in which the line of numbers, from 1 to 10, is laid down *twice* on the A line, it is manifestly necessary only to disregard one-half of this line, and work with a single section of it.

It is evident, however, that, as regards the A lines, the ordinary rules are made twice as long as they need be, only to be encumbered with an useless repetition of the numbers laid down on them.

* Professor de Morgan.

As regards the C and D lines, there is a very serious defect in the ordinary construction; for, except in the case in which the slide is laid evenly in the groove, so that the 1 on the first section of the C line and the 10 on its second section coincide with the 1 and 10 on the D line, there are always portions of the D line which lie beyond the C line at one end, and fall short of it at the other, so that numerous problems cannot be *directly* solved. Their direct solution would require, in fact, an additional section to be added to the C line. With the diminished length of the rule in the Coulson form of its construction, the D line being laid down, half above and half below the groove for the slide, this defect is supplied, as a third section is by this means practically added to the C line, as will be seen in the text (p. 116).

The rules for the numeration of results have been extended to the C and D line (pp. 114—117) with but little addition to their complexity, and the Author flatters himself that he has thus added greatly to the practical utility of the instrument, and at the same time clearly pointed out the advantages of the form devised by Mr. Coulson.

It is remarkable that this form appears to have been designed solely with a view to the reduction of the length of the rule, its designer only claiming for it that with a nine-inch rule all the advantages are obtained of a rule of the ordinary construction of double the length.

In the preparation of this new edition the Author has received valuable assistance from several of the most eminent instrument-makers, and from personal examination and experience of the instruments treated of is enabled to hold himself responsible for the correctness of the description of their construction, and of the modes of testing, adjusting, and using them, herein laid down.

Messrs. Dring and Fage supplied the Author with numerous rules and gauges of their manufacture, and he originally contemplated including in the second part of the volume an account of the instruments used in gauging and measuring casks; but he found that to treat this subject, which is somewhat complex, in such a manner as he would have wished, would have required considerable space, and, in fact, that it would not be possible to do justice to it within the limits which he could allow himself.

Messrs. Elliott have not only afforded him every facility

for the inspection and study of numerous instruments constructed by them, but have also kindly made drawings for him of the spherometer, extensometer, and German-silver wire gauge, &c., and liberally allowed him the use of numerous woodcuts for the illustration of the work.

The Author cannot here forbear from calling particular attention to a little instrument called a polar planimeter (pp. 80—87), manufactured under a Swiss patent, and for which Messrs. Elliott are the sole agents in this country. He knows not whether he was agreeably surprised more by the remarkable geometrical property on which its construction is founded, the neatness and facility with which this principle jumps, as it were, from the theorem proved in Euclid, Bk. ii. props. 12 and 13, the simple manner in which it has been applied to the production of the planimeter, the beautiful manufacture of the little instrument itself, or the wonderful accuracy with which it performs its duty.

Messrs. Parkes and Son, of Birmingham, have assisted the Author by forwarding him a large number of instruments of their manufacture, and he will again have occasion to acknowledge their assistance in the succeeding volumes.

In returning his sincerest thanks to these gentlemen, and others who have assisted him in his task, the Author is compelled to acknowledge that he has been most liberally supplied with the best material, and can only hope that the skill of the workman may not appear to have been altogether inadequate to its manipulation.

J. F. H.

WATFORD,
November, 1870.

PREFACE TO THE FIRST EDITION.

AN attempt has been made in the following pages to put within the reach of all a short and compendious treatise upon some of the ingenious instruments by which the scientific practitioner is aided in his observations, and in the delineation of the results obtained from them.

The instruments treated of have been divided into five classes, to each of which a part of the work has been devoted. The first part treats of Mathematical Drawing Instruments; the second, of Optical Instruments; the third, of Surveying Instruments; the fourth, of Astronomical Instruments; and the fifth, and last, of Goniometrical Instruments, for measuring the angles of crystals.

The greater part of the Wood Engravings, and some parts of the Text, of Simms's Mathematical Drawing Instruments, have been pressed into the service of the present work; and the works of the best writers upon the several parts of the subject have been consulted, and much valuable matter has been extracted from them, particularly from Pearson's Astronomy.

The limits of the bulk and cost of the work have forbidden any extensive excursion into the sciences in which the instruments are used; but it is hoped that a large mass of information has here been placed in a small compass without sacrificing perspicuity to undue compression.

J. F. H.

ROYAL MILITARY ACADEMY, WOOLWICH.
March, 1849.

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MATHEMATICAL INSTRUMENTS.

PART I.

ON MATHEMATICAL DRAWING INSTRUMENTS.

CHAPTER I.

THE DRAWING-BOARD, PAPER, AND PENS.

THE DRAWING BOARD.

THE first thing to be done, preparatory to the commencement of a drawing, is to stretch the paper evenly upon the smooth and flat surface of a drawing board. The edges of the paper should first be cut straight, and, as nearly as possible, at right angles with each other; also the sheet should be so much larger than the intended drawing and its margin, as to

MR. J. F. HEATHER, M.A., late Mathematical Master at the Royal Military Academy, receives pupils, and undertakes their preparation for the Army, for the Indian Civil Engineering College, for the Civil Service, or for the Universities.

WATERFIELD LODGE,
WATFORD, HERTS.

must now be held firm, while the said projecting half inch of paper is turned up along its edge; then, a piece of solid glue (common glue will answer the purpose), having its edge partially dissolved by holding it in boiling water for a few seconds, must be passed once or twice along the turned edge of the paper, after which this glued border must be again laid flat by sliding the rule over it, and, the ruler being pressed down upon it, the edge of the paper will adhere to the board. If sufficient glue has been applied, the ruler may be removed directly, and the edge finally rubbed down by an ivory book-knife, or any clean polished substance at hand, which will then firmly cement the paper to the board. Another but *adjoining* edge of the paper must, next, be acted upon in like manner, and then the remaining edges in succession; we say the adjoining edges, because we have occasionally observed that, when the opposite and parallel edges have been laid down first, without continuing the process progressively round the board, a greater degree of care is required to prevent undulations in the paper as it dries.

Sometimes strong paste is used instead of glue; but, as this takes a longer time to set, it is usual to wet the paper also on the upper surface to within an inch of the paste mark, care being taken not to rub or injure the surface in the process. The wetting of the paper in either case is for the purpose of expanding it; and the edges being fixed to the board in its enlarged state, act as stretchers upon the paper while it contracts in drying, which it should be allowed to do gradually. All creases or undulations by this means disappear from the surface, and it forms a smooth plane to receive the drawing.

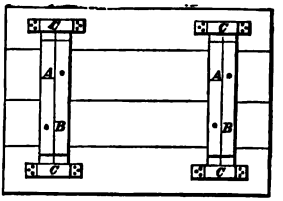
TABLE OF DIMENSIONS OF DRAWING PAPER.

Demy . . .	20	in. by 15½	in.	Columbier .	35	in. by 23½	in.
Medium . .	22½	„ 17½	„	Atlas . . .	34	„ 26	
Royal . . .	24	„ 19	„	Dbl. Elephant	40	„ 27	
Super Royal .	27½	„ 19½	„	Antiquarian .	53	„ 31	
Imperial . .	30	„ 22	„	Emperor . .	68	„ 48	
Elephant . .	28	„ 23	„				

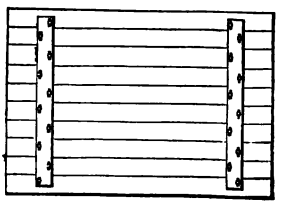
The requisites of a good drawing board are (1) that its surface should be perfectly level, and should remain so under all changes of temperature; (2) that its edges should be straight and well squared; (3) that it should be as light as it can be conveniently made to fulfil the preceding condi-

tions. Unfortunately, all woods will expand and contract laterally under the influence of variations in temperature, and as drawing boards are constantly being wetted and then dried by the fire, no attempt to control the alternate expansions and contractions can prevent the warping of the board. The only effective construction, then, must be such as will allow of any possible amount of expansion and contraction, without destroying the even surface of the board. The desired result is perfectly accomplished by the following mode of construction, the invention of Mr. Howlett, late chief draughtsman at the War Office.

The board is made of well-seasoned pine, three-quarters of an inch thick, without knots, well planed and smoothed, the edges being either simply glued together, or tongued and glued. At the back of the board are the cross pieces, or clamps, consisting each of two pieces, A, B, three quarters of an inch thick, passing through the iron straps c c, into which they fit accurately, but through which they can slide stiffly. The width of the board is divided into three parts at the points A and B, and at these points the clamps are screwed firmly to the board. The clamps are cut away at c to a depth equal to or slightly in excess of the thickness of the iron strap, to prevent the latter from injuring the table on which the board is placed for use. This board then may contract and expand laterally without any strain either upon the joints, which consequently remain close, or upon the clamps, which slide through the straps, and they have been found to stand without injury the severest tests to which they could be exposed.



The accompanying illustration represents another mode of construction, which also sets at defiance the evils arising from alternate expansions and contractions. The screws here pass through slots in the clamps, so that while they hold the pieces forming the board firmly against these clamps, they leave them free to expand and



contract laterally, carrying the screws with them through the amount of play allowed them in the slots.

THE DRAWING PEN.

This instrument (Fig. 1) consists of two blades with steel points fixed to a handle; and they are so bent that a sufficient cavity is left between them for the ink, when the ends of the steel points meet close together, or nearly so. In the best construction the blades are set with the points more or less open by means of a mill-headed screw, so as to draw lines of any required fineness or thickness. One of the blades is framed with a joint, so that by taking out the screw the blades may be completely opened, and the points effectively cleaned after use. The ink is to be put between the blades by a common pen, and in using the pen it should be slightly inclined in the direction of the line drawn, and care should be taken that both points touch the paper. The drawing-pen should be kept close to the straight or other guiding edge (see STRAIGHT-EDGE), and held in the same direction during the whole operation of drawing the line.

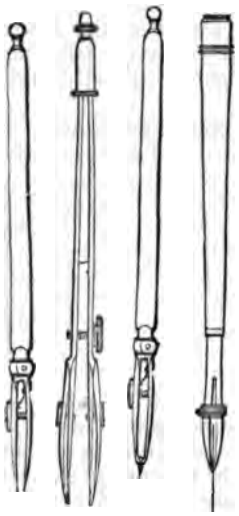


Fig. 1. Fig. 2. Fig. 3. Fig. 4.

For drawing close parallel lines in mechanical and architectural drawings, or to represent canals or roads, a double pen (Fig. 2) is frequently used, with an adjusting screw, to set the pen to any required small distance. This is usually called the road pen. The wheel or dotting pen (Fig. 3), is used for producing dotted lines of different patterns to distinguish the parts of a geometrical construction, or boundaries, back portions of solids, &c. This pen, when the wheel is removed, forms an excellent broad-pointed pen for drawing thick marginal lines. The best pricking point is a fine needle held in a pair of forceps (Fig. 4). It is used to mark the intersections of lines, or to set off divisions from the plotting scale and protractor (pp. 23 and 38). This point may also be used to prick through a drawing upon an intended copy, or, the needle being reversed, the eye end forms a good tracing point.

Letters used to give a description of a drawing, or for the purpose of reference to a written explanation, may be put in very expeditiously by means of stencil plates. These are thin plates of metal having the letters very neatly cut out from them; by laying them on the paper, and brushing the ink over them with a hard brush, it is painted on the paper through the openings, forming a very elegant typography.

CHAPTER II.

INSTRUMENTS FOR DRAWING STRAIGHT LINES.

A STRAIGHT-EDGE.

ALL instruments used for drawing straight lines must be provided with straight edges, and long flat rulers, intended solely for this purpose, are termed straight-edges. They are made of plain mahogany, pear wood, mahogany edged with ebony, or of the very best of steel. It is important in the first place to test the accuracy of such edges. This may be done by placing two such edges in contact and sliding them along each other, while held up between the eye and the light: if the edges fit close in some parts, so as to exclude the light, but admit it to pass between them at other parts, the edges are not true: if, however, the edges appear, as far as the test has now proceeded, to be true, still this may arise from a curvature in one edge fitting into an opposite curvature in the other; the final step then is to take a third edge, and try it in the same manner with each of the other two, and if in each case the contact be close throughout the whole extent of the edges, then they are all three good.*

"To draw a straight line between two points upon a plane, we lay a rule so that the straight edge thereof may just pass by the two points; then moving a fine-pointed needle, or drawing-pen, along this edge, we draw a line from one point to the other, which, for common purposes, is sufficiently exact; but, where great accuracy is required, it will be found extremely difficult to lay the rule equally with respect to both the points, so as not to be nearer to one point than the other. It is difficult also so to carry the needle, or pen, that it shall

* Euclid bk. i. axiom 10. Peacock's Algebra, 1st edition, art. 532. p. 429.

incline neither towards the rule nor from it; and thirdly, it, is very difficult to find a rule that shall be perfectly straight."*

A right line should never be obtained by the prolongation of a very short one, unless some point in that prolongation is first found by some other means, especially in any essential part of a problem.

All lines, perpendicular or parallel to another, should be drawn long enough at first.

Whenever a line is required to be drawn to a point, in order to insure the coincidence of them, it is better to commence the line from the point; and if the line is to pass through two points, before drawing it the pencil should be moved along the rule, so as to ascertain whether the line will, when drawn, pass through them both. If several radii to a circle are required to pass through any number of points respectively, the lines should be begun from the centre of the circle; any error being more obvious when several lines meet in a point.

"If the two points be very far distant, it is almost impossible to draw the line with accuracy and exactness; a circular line may be described more easily, and more exactly, than a straight or any other line, though even then many difficulties occur, when the circle is required to be of a large radius.

"And let no one consider these reflections as the effect of too scrupulous exactness, or as an unnecessary aim at precision; for, as the foundation of all our knowledge in geography, navigation, and astronomy, is built on observations, and all observations are made with instruments, it follows that the truth of the observations, and the accuracy of the deductions therefrom, will principally depend on the exactness with which the instruments are made and divided, and that those sciences will advance in proportion as these are less difficult in their use, and more perfect in the performance of their respective operations."*

BOW LINE.

This is merely a slip of wood which has a small piece of hard wood fastened upon one side of it at each end, across which a fine wire is drawn; a plain key at the back of the

* Geometrical and Graphical Essays, by George Adams, jun., edited by William Jones.

lath, similar to the key of a violin, will tighten the wire to any degree. It is used when a line considerably longer than the straight-edge is required. To produce a long line with it, marks must be made exactly under the line at distances apart that a straight edge will reach; the bow line is then removed, and the straight edge is used to produce the line.

PARALLEL RULES.

Lines are drawn parallel to each other with the greatest facility and accuracy, either by means of a triangle and straight-edge, or by the T-square; but rolling parallel rules are also much used by professional draughtsmen. They will produce parallel lines in any direction; they move freely and admit of rapid use. The accuracy of the work can also be readily tested by running the rule back to the original line, and again by turning the rule round end for end and repeating the operation.

THE T-SQUARE.

This instrument consists of a blade A, which forms the straight-edge, and the stock B, which guides its motion and has its guiding edge set accurately at right angles to the straight edge of the blade. The following are the two most useful forms of this instrument.

In Fig. (1) the stock is on one side flush with the blade, and on the other projects beyond it, forming a rabbet which passes over the edge of the drawing board, and being gently pressed against it, guides the straight-edge, and enables us to draw lines *c*, *c*, *d*, *d*, throughout the whole extent of the paper, at right angles, to the edges of the drawing board, and consequently parallel and perpendicular to each other.

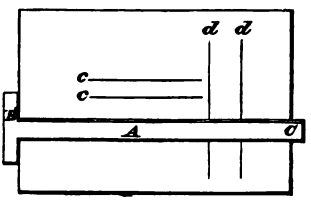


Fig. 1.

In the absence of a *good* drawing board, this T-square may be turned over and worked against a straight-edge clamped to a drawing board or a table.

In Fig. (2) the square is merely a blade screwed upon a stock without being either sunk or mortised into it. This form can be used only with a *good* drawing board; but it

allows the set square to pass over the head, so as to be used for drawing lines close up to the edge of the drawing board. The instrument makers also supply movable head squares to

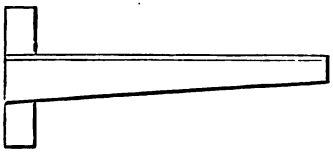
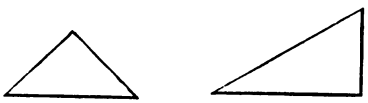


Fig. 2

form bevels for drawing oblique parallel lines. One of these has a graduated arm attached to the blade, for setting the stock at any desired angle with it.

THE TRIANGLE OR SET SQUARE.

For drawing parallel lines of short lengths, and in any directions the best instrument is a triangle worked against a straight edge. They are made with angles of various sizes, but the most useful are those with angles of 45° and 30°,

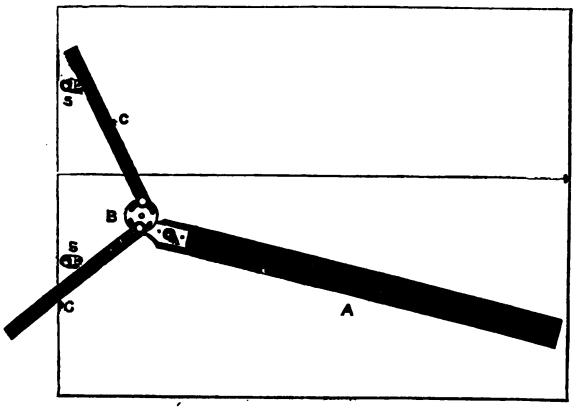


and the triangle of the Marquois's scales. The angle of 30° enables us at once to draw all the principal lines in an isometrical drawing.

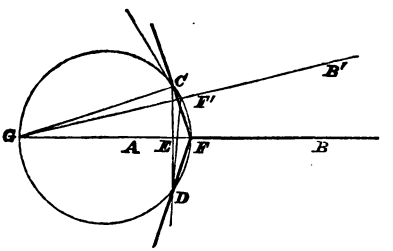
THE CENTROLINEAD.

In the perspective representation of objects, all parallel lines in the object represented, which are not at the same time parallel to the plane of the picture, upon which they are to be represented, must be so drawn as to meet in a point, which is denominated the vanishing point. This point is generally so distant as to require a very long straight-edge and drawing board to produce the lines, and often to render even this mode impracticable, and necessitate a troublesome geometrical construction for each line to be drawn. A convenient instrument for drawing lines which shall all converge to the same point, no matter how distant, is, therefore, a very great desideratum, and in the centrolinead we have an instru-

ment of very simple construction, which perfectly accomplishes this object. It consists of a rule A, with a straight edge, to which a circular head B is so fitted that the prolongation of the straight edge would pass exactly through its centre. To this head two arms, c c, of equal length are



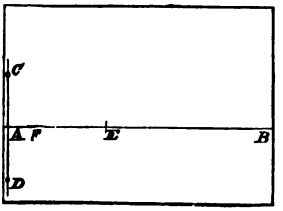
jointed so as to have their working edges, which are the edges farthest from the rule, also each in line with the centre of the head. These arms can be moved into any desired position, and then securely clamped. They work against two studs, s s, which are to be fixed to the drawing board.



Now if A B and C D be two lines at right angles to each other, intersecting in E, and if the instrument be set so that its straight edge B F may coincide with A B, while the arms lie

against the studs placed at the points C and D equally distant from A B, and the arms be then clamped, as the instrument is moved, keeping the arms in contact with the studs, the centre of the head will describe a circular arc* C F D, whose diameter F G will be found by drawing C G at right angles to C F, intersecting B A produced in G,† through which point the prolongation of the straight edge, when moved into any new position, B′ F′, will always pass.

The point E in a picture to which the eye is supposed to be directly opposite is called the centre of the picture; and a line A B drawn through this point parallel to the base of the picture is called *the horizontal line*, and the vanishing points for all horizontal lines lie upon this line or its production.



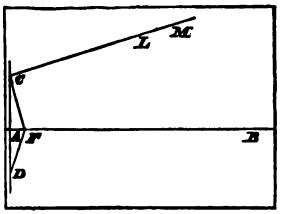
To set the centrolinead so as to draw a series of horizontal lines converging to a given vanishing point. The horizontal line A B must be first drawn, and then a line C A D at right angles to it, as near as possible to the edge of the drawing board on that side beyond which the vanishing point is to lie. Upon C D set off the points C, D, upon which to place the studs, equally distant from A, and as far apart as the dimensions of the instrument and the drawing board will permit, and as will be convenient for the next step. Set off A F the same part of A C or A D that these distances are of the required distance from A of the vanishing point, and the arms being unclamped, place the straight edge in coincidence with the horizontal line A B, so that the centre of the head may coincide with the point F, and bringing the arms to bear against the studs at C and D, clamp them in this position, and the instrument will be set as desired.

Ex.—To make the lines converge to a vanishing point 4 feet distant from A, make the distances A C and A D each 8 inches for the stud points, and 8 inches being the sixth part of 4 feet, set off A F equal to $1\frac{1}{3}$ inches, which is the sixth part of 8 inches, for the centre of the head.

A Line to represent one Horizontal Line in a picture being already drawn, to set the instrument so as to draw all other Lines in the picture which are Parallel to it.—Let L M be a

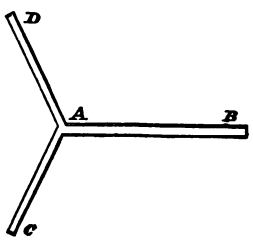
* Euclid iii. 21. † Euclid iii. 31.

line drawn to represent one horizontal line in a drawing, the top of a building suppose; draw C D at right angles to the horizontal line A B, and place the centrolinead so as to have its straight edge coincident with L M, and one of its arms coincident with C D; clamp this arm, and fix the studs, one at C and the other at D, making A D equal to A C; now move the instrument so as to bring the straight edge into coincidence with A B, while the clamped arm bears against the stud at D, and clamping the other arm so as to bear against the stud at C, the instrument will be set as desired.



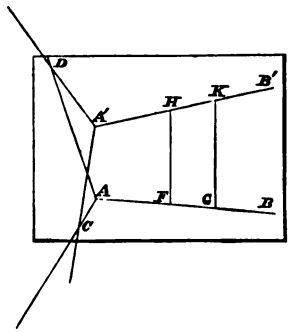
If the prolongation of the line L M to C should make A C inconveniently short, this distance may be multiplied by any quantity, provided A F be multiplied by the square of the same quantity: thus if A C be doubled A F must be four times as great as before, and if A C be trebled A F must be made nine time as great as before, and the instrument will still produce lines converging to the same point.

The instrument might also be set by placing the straight edge in coincidence with A B, and one of the arms with a line at right angles to L M, upon which line the studs would have to be fixed; but this would generally place the studs in an inconvenient position. In a similar manner the instrument may be set to draw any other series of lines to represent oblique parallels, when two lines of the series are determined.



There is a simpler form of centrolinead in which the arms A C, A D, and the straight edge A B are all formed in one piece. The mode of setting this instrument will be seen to be extremely simple; but as the angle of the arms is invariable, the distance of the vanishing point can only be regulated by the distance the pins are placed apart. This distance will for a near vanishing point be inconveniently short, while for a distant vanishing point it will become inconveniently great, and, in fact, may not come within the limits of the drawing board.

Two Lines to represent Parallel Lines being already drawn in a picture, to set the pins for this instrument so as to draw any Number of Lines to represent Lines Parallel to them.—Let F G and H K be two lines in the picture, representing parallels. Bring the straight edge first into coincidence with F G, and draw pencil lines A C, A D, along the guiding edges of the two arms; again bring the straight edge into coincidence with H K, and draw pencil lines A′ C, and A′ D, along the guiding edges of the arms in their new position; then fixing the pins at the points C and D, in which the pencil lines intersect, they will be correctly set for drawing lines to represent parallels to F G and H K.



If it be desired to make the lines have a given vanishing point two lines must first be drawn vanishing at the point proposed, and the pins be then set by means of these lines in the manner explained above. The two lines required may be drawn thus:—Draw a line F G, the prolongation of which would pass through the desired vanishing point, and make the distance F G an aliquot part of the desired distance of the vanishing point from F; through F and G draw F H and G K parallel to one another, and of such length that the excess of G K above F H, may be the same aliquot part of F H that F G is of the distance of the vanishing point from F; and joining H K, H K and F G will be such lines as were required.

A ruler similar in appearance to the rolling parallel ruler, but rolling upon wheels at each end, which have different diameters, also forms a simple centrolinead.

CHAPTER III.

INSTRUMENTS FOR DRAWING CURVED LINES.

DRAWING COMPASSES.

This instrument consists of two legs movable about a joint, so that the points at the extremities of the legs may be set at any required distance from one another; it is used to take and transfer distances, and to describe arcs and circles. When used for the former purpose they are termed dividers.

The points of the compasses Figs. (1 and 2) should be formed of well-tempered steel, that cannot be easily bent or blunted, the upper part being formed of brass or silver. The joint is formed of two substances; one side being of the same material as the upper part of the compasses, either brass or silver, and the other of steel. This arrangement diminishes the wear of the parts, and promotes uniformity in their motion. If this uniformity be wanting, it is extremely difficult to set the compasses at any desired distance, for, being opened or closed by the pressure of the finger, if the joint be not good, they will move by fits and starts, and either stop short of, or go beyond the distance required; but, when they move evenly, the pressure may be regulated so as to open the legs to the desired extent, and the joint should be stiff enough to hold them in this position, and not to permit them to deviate from it in consequence of the small amount of pressure which is inseparable from their use.

Fig. 1.

Fig. 2.

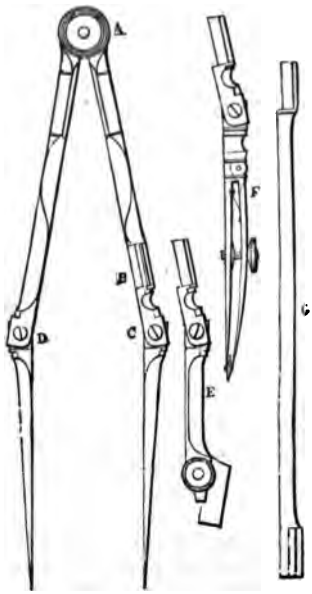
Fig. 3.

Fig. (3) represents a key of which the two points fit into the two holes seen in the nut *n*, of the joint; and by turning this nut the joint is made stiffer or easier at pleasure.

In the cases of drawing instruments usually sold by the mathematical instrument maker are inserted what are called *hair compasses*, intended by means of a second adjustment to afford greater accuracy in the setting of the points than can be effected by the joint alone; but the precision supposed to be derived from this arrangement is fallacious, while the weakness of the point on which the additional adjustment acts is a positive disadvantage.

COMPASSES WITH MOVABLE POINTS.

If an arc or circle is to be described faintly, merely as a guide for the terminating points of other lines, the steel points are generally sufficient for the purpose, and are susceptible of adjustment with greater accuracy than a pencil point; but, in order to draw arcs or circles with ink or black lead, compasses with a movable point are used. In the best description of these compasses the end of the shank is formed into a strong spring, which holds firmly the movable point, or a pencil or ink point, as may be required. A lengthening bar may also be attached between the shank and the movable point, so as to strike larger circles, and measure greater distances. The movable point to be attached to the lengthening bar, as also the pen point and pencil point, are furnished with a joint, that they may be set nearly perpendicular to the paper.



A, the compasses, with a movable point at B.

C and D, the joints to set each point perpendicular to the paper.

E, the pencil point.

F, the pen point. (This is represented with a dotting

wheel, the pen point and the dotting point being similar in shape to each other.)

G, the lengthening bar.

(1.) In using the compasses either as dividers or for drawing arcs or circles, care should be taken so to hold them, that the distance between the points should not be altered by the pressure of the fingers. A good position is given by placing the forefinger upon the head, and the second finger and thumb on the flat sides of the joint. In dividing a line it is better to move the dividers alternately above and below the line from each point of division, than to roll them over continually in one direction; as it saves the shifting of the fingers on the head of the dividers. In taking off distances with dividers it is always better first to open them a little too wide, and afterwards close them to the point required, than to set them by opening.

(2.) Arcs of circles, or right lines by which an important point is to be found, should never intersect each other very obliquely, or at an angle of less than 15 or 20 degrees; and, if this cannot be avoided, some other process should be had recourse to, to define the point more precisely.

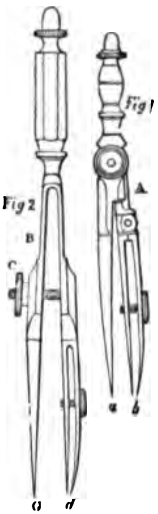
(3.) When one arc of a circle is described, and a point in it is to be determined by the intersection of another arc, this latter need not be drawn at all, but only the point marked off on the first, as it is always desirable to avoid the drawing of unnecessary lines. The same observation applies to a point to be determined on one straight line by the intersection of another.

(4.) Whenever the compasses can be used in any part of a construction, or to construct the whole problem, they are to be preferred to the straight edge, unless the process is much more circuitous, or unless the second rule (above) forbids.

(5.) The larger the scale on which any problem, or any part of one, is constructed, the less is the result liable to error; hence all angles should be set off on the largest circles which circumstances will admit of being described, and the largest radius should be taken to describe the arcs by which to find a point through which a right line is to be drawn; and the greater attention is to be paid to this rule, in proportion as that step of the problem under consideration is conducive to the correctness of the final result.

To describe small arcs or circles a small pair of compasses, called *bow compasses*, with a permanent ink or pencil point,

are used. They are formed with a round head, which rolls with ease between the fingers. The adjoining figures represent two constructions of pen bows, Fig. 1 being well adapted to describe arcs of not more than one inch radius, and Fig. 2 to describe arcs of small radii with exactness by means of the adjusting screw c.

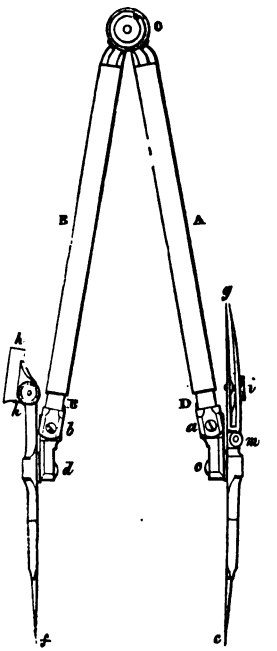


HORN CENTRES.

These are useful when many circles or arcs are to be struck from one centre, as they enable us to do so without injuring the paper beneath them by the continual working of the compass point upon the same spot. They consist merely of a small circular piece of thin horn, with small pins in the under side to prevent them from slipping when placed on the paper.

TUBULAR COMPASSES.

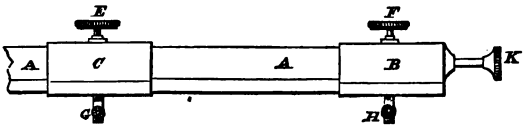
When the lengthening bar is used to describe large arcs, or take off long distances, the instrument is wanting in firmness and steadiness, and the object is better accomplished by the use of the tubular compasses, in which the legs consist of two tubes, each containing an inner tube or bar, which slides out like a telescope tube. These compasses, however, are not much used, the beam compasses which we proceed to describe being far preferable for taking off any but comparatively



small distances, or describing arcs with any but comparatively small radii.

BEAM COMPASSES.

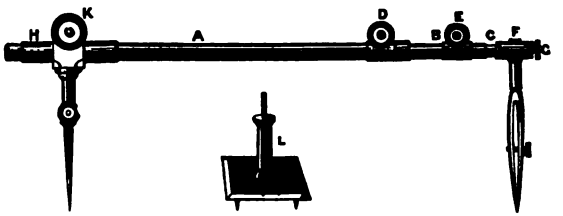
This instrument consists of a beam A A, of any length required, sometimes as much as six feet, the most usual lengths, however, being two, three, and four feet. Upon its face is sometimes inlaid throughout its whole length a slip of holly or boxwood, upon which are engraved the divisions of a scale.



The advantages of such a scale are, however, doubtful for any purpose, since if the points be not perfectly parallel, and accurate in all respects, the distance between them will not accord with that indicated on the scale. For the draughtsman such a scale is actually a disadvantage, as he is apt to make use of it in filling in his work instead of setting his points by scales previously laid down on his paper, so as to expand and contract with it; for it must be borne in mind that paper is liable to expansion and contraction, as the air happens to be moist or dry, and the larger the lines to be laid down, the greater the errors that will arise from setting them off by an independent scale. Two scales should therefore be first laid down upon the paper, parallel to two of its adjacent edges. These scales expand and contract equally with the rest of the paper, according to the hydrometric state of the atmosphere; and the distances set off by their means will therefore always have their proper relative values. In laying down these scales the distances may be set off by applying the points of the compass to a good independent scale. To carry these points the instrument is furnished with two brass boxes, B and C, the first of which is fixed to one end of the beam, while the latter may be moved by sliding to any part of its length, and then fixed in position by turning the clamp screw E. To each of these boxes is attached a tube for holding one of the needle points, or a pen or pencil point as may be desired, and these points are firmly fixed in position by clamping screws, G and H. K is a tangent screw for giving

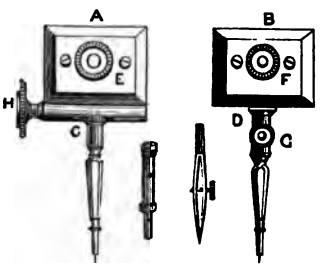
a slow motion to the box B, after it has been clamped by the screw F, and thus producing a more accurate adjustment.

In tubular beam compasses, a series of tubes, as A, B, C, slide one within the other, like the tubes of a telescope, and when pulled out so as to allow the boxes holding the points to be set at the desired distance, are fixed in this position by the clamping screws D and E. One of the boxes, F, is fixed at the



smaller end of the beam, and adjusted accurately by a tangent screw G, while the other box H slides upon the outside tube, which forms the larger end of the beam, and is fixed in any desired position by the clamping screw K. A universal centre is supplied with the instrument, the top of which fits into one of the boxes in place of the point, and thus enables the draughtsman to draw circles without making large holes in the paper. It in fact performs the same duty as the horn centre does for the ordinary compasses.

A very useful, if not the most useful, form of beam com-



pass, called the portable beam compass, consists merely of boxes A, B, with tubes, C, D, for holding the points, and clamps, E, F, by which they may be fixed upon a lath or brass

beam of any length. The tube D of the box B has a clamping screw G, by means of which the point inserted into this tube may be fixed when pushed more or less into the tube, so as to adjust it in accordance with the point inserted in the tube C of the box A. To the box A is also attached a tangent screw H, for giving a small motion to the tube C, and the point it carries, after the clamping of the boxes upon the lath or beam. The beam compasses above described form the most perfect instrument for describing arcs of circles of the largest radii that can ever be required by the draughtsman; but we proceed to explain a manner in which the same object may be accomplished without travelling beyond the limits of the drawing board.

By Euclid iii. 36, the angles in the same segment of a circle are equal to one another, and the property demonstrated in this theorem has already been applied in the construction of the centrolinead, in which the centre of the head describes a circular arc, the centre of which is on the production of the horizontal or other line to which the straight-edge is adjusted for setting the instrument. By an application of the same property we may produce an arc of any radius, or which will pass through any three points. Thus if A, B, C be the three points through which it is desired to describe an arc; join C A and C B and produce them to D and E until C D and C E each exceed A B in length; then cutting a triangle of thin wood or card-board of the same dimensions as D, C, E, and moving it between two pins fixed at A and B, a pencil held at the apex C of the triangle will describe the desired arc. If in cutting the triangle a small circular head be left at the apex, and the point of the pencil be protruded through a pin-hole at the vertex C, a very good instrument for the desired purpose will be produced.

Mr. Stanley has attempted to produce an instrument which should form a universal triangle for describing arcs of large radii; and his instrument, which he calls a centograph, does give an approximation to a circular arc; but the ink or pencil point not being placed at the vertex of the angle, the curve described is not really an arc of any circle whatever.

Instead of drawing arcs of large radii upon the paper by the immediate use of the beam compass, templets may first be

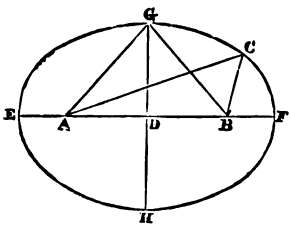
cut out in wood by means of the compass, and then used as guiding edges for drawing the arcs.

Templets may also be procured from the instrument makers, cut into the form of almost every curve required by the draughtsman either for architectural ornament, or the lines of ship-building.

We proceed to make a few remarks on the mode of describing those of the curves having known geometrical properties, which are the most important to the draughtsman.

THE ELLIPSE.

This curve can be described by what is called the gardener's method. Two pins are fixed at the points A and B, which are called the foci of the ellipse, and a string A C B is attached



to these pins; a pencil is then moved round, keeping it always pressed against the string so that the sum of the distance A C and C B is constant.

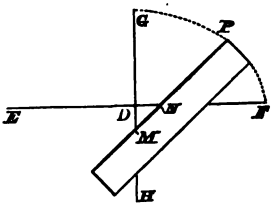
If the lines E F and G H be drawn so as to intersect at right angles and mutually bisect each other in D, E F is called the major axis of the ellipse, G H its minor axis, and D its centre.

To find the foci when the axes are given, we have only to set off from one extremity, G, of the minor axis, the distances G A and G B, each equal the semi-major axis D E or D F, and the points A and B thus found will be the foci required.

The best mode, however, to be employed by the draughtsman for drawing an ellipse is the following:—

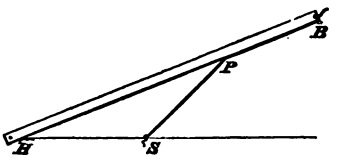
The axes E F and G H being first drawn, take a strip of paper with a straight edge M N P, and on it mark off M P and N P equal to the semi-axes D F and D G respectively; then if this strip of paper be moved round into different positions but so

that the point M shall always lie on G H, and the point N on E F, the extremity P of the slip will determine a series of points in the ellipse, and the curve must then be drawn through these points. Upon the principle of the mode just explained, instruments called elliptographs have been constructed, in which a rod, filling the office of our piece of paper, has pins attached to it at the points M and N, which slide through grooves in a cross, which represents the axes. There are two constructions of the instrument, one for drawing large ellipses in which the describing point P necessarily passes outside the arms of the cross, and the other, called Farey's Elliptograph, in which the rod is placed beneath the cross between it and the paper, so that the describing point works within the cross, and very small ellipses can be described with it. Such instruments, however, do not work satisfactorily, and we cannot recommend them in preference to the modes above described.



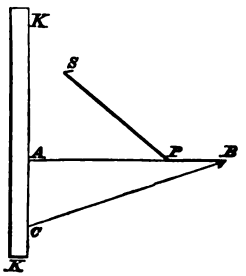
THE HYPERBOLA.

The hyperbola is the curve traced out by a point that moves so that the difference between the focal distances H P and S P is a constant quantity; it may therefore be thus described. Take a straight-edge and fix a string S P B to it at some point B, as remote as may be desired for the portion of the curve to be described; fix the other end of the string to a pin S, which point will form one of the foci of the curve; let a needle point be passed through the rod at H, and placed upon the paper, the point at which it meets the paper will be the other focus of the curve; then a pencil moved along the rod B P, so as to keep the portion S P of the string always stretched straight, and the portion B P in contact with the rod, while the rod itself moves round H, will trace out the required curve.



THE PARABOLA.

This curve may be traced from the property it possesses, that every point in it is at equal distances from a fixed point, and a line fixed in position. Let S be the fixed point, which is called the focus, and K K the line fixed in position. Place a straight-edge in coincidence with K K, and clamp it; place a set square A B C against the straight-edge, as represented in the figure. Fix a string S P B to a pin at S and to the point B of the set square, so that the length S P B of the string is equal to the length A B of the edge of the square; then a pencil moved so as to keep the portion S P of the string always straight, and the portion P B close against the edge A B of the set square, while the edge A C of this square is kept against the straight edge K K, will describe the curve required.



CHAPTER IV.

INSTRUMENTS FOR TAKING OFF AND LAYING DOWN DISTANCES AND ANGLES.

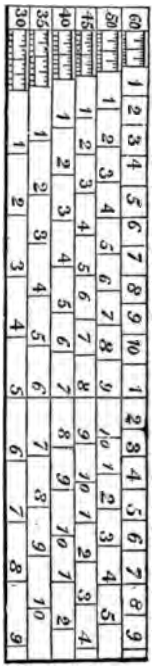
Scales of equal parts are used for measuring straight lines, and laying down distances, each part answering for one foot, one yard, one chain, &c., as may be convenient, and the plan will be larger or smaller as the scale contains a smaller or a greater number of parts in an inch.

Scales of equal parts may be divided into two kinds; simply-divided scales, and diagonal scales.

Simply-divided Scales.—Simply-divided scales consist of any extent of equal divisions, which are numbered 1, 2, 3, &c., beginning from the second division on the left hand. The first of these primary divisions is subdivided into ten equal parts, and from these last divisions the scale is named.

Thus it is called a scale of 30, when thirty of these small parts are equal to one inch. If, then, these subdivisions be taken as units, each to represent one mile, for instance, or one chain, or one foot, &c., the primary divisions will be so many tens of miles, or of chains, or of feet, &c.; if the subdivisions are taken as tens, the primary divisions will be hundreds; and, if the primary divisions be units, the subdivisions will be tenths.

The accompanying drawing represents six simply-divided scales, which are generally placed upon the plain scale (p. 38). To adapt them to feet and inches, the first primary division is divided duodecimally upon an upper line. To lay down 360, or 36, or 3·6, &c., from any one of these scales, extend the compasses from the primary division numbered 3 to the 6th lower sub-division, reckoning backwards, or towards the left hand. To take off any number of feet and inches, 6 feet 7 inches for instance, extend the compasses from the primary division numbered 6, to the 7th upper subdivision, reckoning backwards as before.

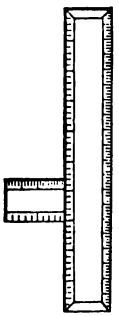


Such simply-divided scales as we have just described are usually placed upon one of the faces of the protractor or plain scale (p. 38) always supplied in the case of instruments; while on the other side are placed scales of inches and parts of inches, as the $\frac{3}{4}$-inch, $\frac{1}{2}$-inch, $\frac{1}{4}$-inch, $\frac{1}{8}$-inch, to represent feet, each of these scales having the first of the primary divisions divided into twelve equal subdivisions to represent inches. These scales have the disadvantage that in using them the divisional marks are liable to injury from the constant application of the points of the dividers.

Plotting scales, also called feather-edged scales, are straight rulers, usually about ten or twelve inches long. Each ruler has scales of equal parts, decimally divided, placed upon its edges, which are made sloping, so that the extremities of the strokes marking the divisions lie close to the paper. The primary divisions represent chains, and the subdivisions,

consequently, ten links each, as there are 100 links on the surveying chain. Plotting scales may be procured in sets, each with a different number of chains to the inch.

The advantages of this arrangement are, that the distances required can be transferred with great expedition from the scale to the paper by the aid of the pricking-point alone, and the marks denoting the divisions are in no danger of becoming defaced, as upon the plain scale, by the frequent application of the compasses.



With each plotting scale, a small scale called an offsetting scale is generally supplied, which is worked along the edge of the plotting scale, as represented in the accompanying illustration, to set off distances from the main lines laid down by the plotting scale.

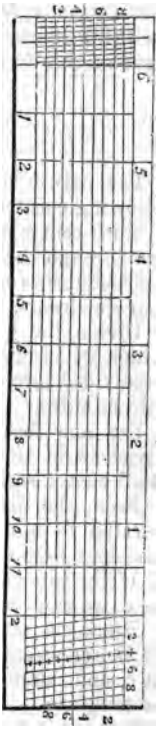
Diagonal Scales.—In the simply-divided scales one of the primary divisions is subdivided only into ten equal parts, and the parts of any distance which are less than tenths of a primary division cannot be accurately taken off from them; but, by means of a diagonal scale, the parts of any distance which are the hundredths of the primary divisions are indicated, as will easily be understood from its construction, which we proceed to describe.

Draw eleven parallel equidistant lines; divide the upper of these lines into equal parts of the intended length of the primary divisions; and through each of these divisions draw perpendicular lines, cutting all the eleven parallels, and number these primary divisions, 1, 2, 3, &c., beginning from the second.

Subdivide the first of these primary divisions into ten equal parts, both upon the highest and lowest of the eleven parallel lines, and let these subdivisions be reckoned in the opposite direction to the primary divisions, as in the simply-divided scales.

Draw the diagonal lines from the tenth subdivision below to the ninth above; from the ninth below to the eighth above; and so on; till we come to a line from the first below to the zero point above. Then, since these diagonal lines are all parallel, and consequently everywhere equidistant, the distance between any two of them in succession, measured upon

of the eleven parallel lines which they intersect, is the as this distance measured upon the highest or lowest of lines, that is, as one of the subdivisions before mentioned; the distance between the perpendicular, which passes igh the zero point, and the diagonal igh the same point, being nothing on highest line, and equal to one of the ivisions on the lowest line, is equal lid vi. prop. 4) to one-tenth of a subdi- n on the second line, two-tenths of a ivision on the third, and so on; so this, and consequently each of the diagonal lines, as it reaches each ssive parallel, separates further from perpendicular through the zero point ie-tenth of the extent of a subdivision, ie-hundredth of the extent of a pri- division. Our figure represents the liagonal scales which are usually placed the plane scale of six inches in length. ie, the distances between the primary ions are each half an inch, and in the a quarter of an inch. The parallel to the figures numbering these divi- must be considered the highest or first lel in each of these scales to accord the above description.



e primary divisions being taken for , to set off the numbers 5·74 by the nal scale. Set one foot of the com- s on the point where the fifth parallel the eighth diagonal line, and extend ther foot to the point where the same lel cuts the sixth vertical line.

e primary divisions being reckoned as to take off the number 46·7. Extend the compasses the point where the eighth parallel cuts the seventh nal to the point where it cuts the fifth vertical.

e primary divisions being hundreds, to take off the er 253. Extend the compasses from the point where urth parallel cuts the sixth diagonal to the point where s the third vertical.

w, since the first of the parallels, of the diagonals, and

of the verticals, indicate the zero points for the third, second, and first figures respectively, the second of each of them stands for, and is marked, 1, the third 2, and so on, and we have the following.

General Rule.—To take off any Number to Three Places of figures upon a Diagonal Scale.—On the parallel indicated by the third figure, measure from the diagonal indicated by the second figure to the vertical indicated by the first.

ON THE PROTRACTING SCALES.

The nature of these scales will be understood from the following construction (Plate 1, Fig. 1):—

With centre O, and radius O A, describe the circle A B C D; and through the centre O draw the diameters A C, and B D, at right angles to each other, which will divide the circle into four quadrants, A B, B C, C D, and D A.

Divide the quadrant C D into nine equal parts, each of which will contain ten degrees, and these parts may again be subdivided into degrees, and, if the circle be sufficiently large, into minutes.

Set one foot of the compasses upon C, and transfer the divisions in the quadrant C D, to the right line C D, and we shall have a scale of chords.*

From the divisions in the quadrant C D draw right lines parallel to D O, to cut the radius O C, and, numbering the divisions from O, towards C, we shall have a scale of sines.

If the same divisions be numbered from C, and continued to A, we shall have a scale of versed sines.

From the centre O draw right lines through the divisions of the quadrant C D, to meet the line C T, touching the circle at C, and, numbering from C, towards T, we shall have a scale of tangents.

Set one foot of the compasses upon the centre O, and transfer

* We give the constructions in the text to show the nature of the scales; but in practice a scale of chords is most accurately constructed by values computed from tabulated arithmetical values of sines, which computed values are set off from a scale of equal parts; and the circle is divided most accurately by means of such computed chords. The limits of our work forbid our entering further upon this interesting subject. All the other scales will also be most accurately constructed from computed arithmetical values, taken off by means of the beam compasses from an accurately constructed scale of equal parts.

the divisions in C T into the right line O S, and we shall have a scale of secants.

Right lines, drawn from A to the several divisions in the quadrant C D, will divide the radius O D into a line of semi-tangents, or tangents of half the angles indicated by the numbers; and the scale may be continued by continuing the divisions from the quadrant C D through the quadrant D A, and drawing right lines from A, through these divisions, to meet the radius O D, produced.

Divide the quadrant A D into eight equal parts, subdivide each of these into four equal parts, and, setting one foot of the compasses upon A, transfer these divisions to the right line A D, and we shall have a scale of rhumbs.

Divide the radius A O into 60 equal parts, and number them from O towards A; through these divisions draw right lines parallel to the radius OB, to meet the quadrant A B; and, with one foot of the compasses upon A, transfer these divisions from the quadrant to the line A B, and we shall have a scale of longitudes.

* Place the chord of 60°, or radius,† between the radii O C and OB, meeting them at equal distances from the centre; divide the quadrant C B into six equal parts, for intervals of hours, subdividing each of these parts into twelve for intervals of five minutes, and further subdividing for single minutes if the circle be large enough; and from the centre O draw right lines to the divisions and subdivisions of the quadrant, and we shall have a scale of hours.

Prolong the touching line T C to L; set off the scale of sines from C to L; draw right lines from the centre O to the divisions upon C L, and from the intersections of these lines with the quadrant C B draw right lines parallel to the radius O C, to meet the radius O B, and we shall have a scale of latitudes. ‡

* The constructions in this and the following paragraphs are not given in the figure, being superseded by the constructions given on the next page.

† Chord of 60° is equal to radius. Euclid iv. 15, Cor.

‡ The line of latitudes is a line of sines (to radius equal the whole length of the line of hours) of the angles, of which the tangents are equal to the sines of the latitudes. The middle of the hour line being numbered for three o'clock, the divisions for the other hours are found by setting off both ways from the middle the tangents of *n*. 15°, *n*. being the number of hours from three o'clock, that is, one for two o'clock and four o'clock, two for one o'clock and five o'clock, and three for twelve o'clock and six o'clock.

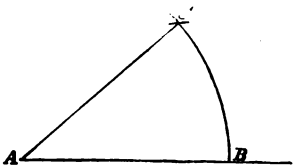
Corresponding lines of hours and latitudes may also be constructed (as represented in our figure) more simply, and on a scale twice as large as by the preceding method, as follows:—

With the chord of 45° set off from B to E, and again from B to F, we obtain a quadrant E F bisected in B; and, the chord of 60° or radius being set off from A, C, F, and E, this quadrant is divided into six equal parts. From the centre O draw straight lines through these divisions to meet the line touching the circle at B, and we shall have the line of hours.

From the point D draw right lines through the divisions upon the line of sines O C, to meet the circumference B C, and transferring these divisions from B, as a centre to the chord B C, we shall have the corresponding line of latitudes.

It is not necessary that these scales should all be projected to the same radius; but those which are used together, as the rhumbs and chords, the chords and longitudes, the sines, tangents, secants, and semitangents, and lastly, the hours and latitudes, must be so constructed necessarily. In the accompanying diagram (Plate 1, Fig. 2) we have laid down the hours and latitudes to a radius equal to the whole length of the scale, the other lines being laid down to the radius used in the foregoing construction.

The Line of Chords is used to set off an angle, or to measure an angle already laid down.

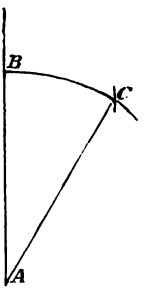


1st. *To set off an angle*, which shall contain D° from the point A, in the straight line A B. Open the compasses to the extent of 60° upon the line of chords, which equals the radius to which this line has been laid down (Euclid iv. prop. 15, Cor.), and, setting one foot upon A, with this extent describe an arc cutting A B in B; then, taking the extent of D° from the same line of chords, set it off from B to C; and, joining A C, B A C is the angle required. Thus, to set off an angle of 41°, having described the arc B C, as directed, with one foot of the compasses on B, and the extent of 41° on the line of chords, intersect B C in C, and join A C.

2nd. *To measure the angle contained by the straight lines* A B *and* A C *already laid down.*—Open the compasses to the

extent of 60° on the line of chords, as before, and with this radius describe the arc B C, cutting A B and A C, produced, if necessary, in the points B and C; then, extending the compasses from B to C, place one point of the compasses on the beginning, or zero point, of the line of chords, and the other point will extend to the number upon this line, indicating the degrees in the angle B A C. If, for instance, this point fall on the 41st division, or the first division beyond that marked 40 in the figure (Plate 1, Fig. 2), the angle B A C will contain 41°.

The Line of Rhumbs is a scale of the chords of the angles of deviation from the meridian denoted by the several points and quarter points of the compass, enabling the navigator, without computation, to lay down or measure a ship's course upon a chart. Thus, supposing the ship's course to be N.N.E. ¼ E. Through the point A, representing the ship's place upon the chart, draw the meridian A B, and with centre A and distance equal to the extent of 60° upon the line of chords describe an arc cutting A B in B; then on the line of rhumbs take the extent to the third subdivision beyond the division marked 2, because N.N.E. is the second point of the compass from the north, and with one foot of the compasses on B describe an arc intersecting B C in C: join A C, and the angle B A C will represent the ship's course. On the other hand, if a ship is to be sailed from the point A to a point on the line A C on a chart, draw the meridian A B, describe the arc B C with radius equal to chord of 60°, as before, and the extent from B to C, applied to the line of rhumbs, will give 2 pts. 3 qrs., denoting that the ship must be sailed by the compass N.N.E. ¼ E.



The Line of Longitudes shows the number of equatorial miles in a degree of longitude on the parallels of latitude indicated by the degrees on the corresponding points of the line of chords. *Ex.*—A ship in latitude 60° N. sailing E. 79 miles, required the difference of longitude between the beginning and end of her course. Opposite 60 on the line of chords stands 30 on the line of longitudes, which is, therefore, the number of equatorial miles in a degree of longitude

at that latitude. Hence, as 30 : 79 : : 60 : 158 miles, the required difference of longitude.

The Lines of Sines, Secants, Tangents and Semitangents are principally used for the several projections, or perspective representations, of the circles of the sphere, by means of which maps are constructed. Thus, the meridians and parallels of latitude being projected, the countries intended to be represented are traced out according to their respective situations and extent, the position of every point being determined by the intersection of its given meridian and parallel of latitude.

The plane upon which the circles are to be delineated is called the primitive, and the circumference of a circle, described with a radius, representing, upon the reduced scale of the drawing, the radius of the sphere, is called the circumference of the primitive. Lines, drawn from all the points of the circles to the eye, by their intersection with the primitive form the projection.

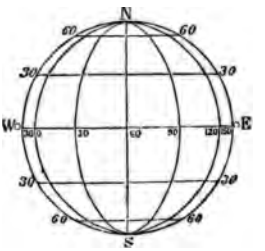
When the eye is supposed to be infinitely distant, so that the lines of vision are parallel to one another and perpendicular to the primitive, the projection is called orthographic. When the primitive is a tangent plane to the sphere, and the eye is supposed to be at the centre of the sphere, the projection is called gnomonic. When the eye is supposed to be at the surface of the sphere, and the primitive to pass through the centre, so as to have the eye in its pole, the projection is called stereographic.

The projection is further termed equatorial, meridional, or horizontal, according as the primitive coincides with, or is parallel to, the equator, or the meridian or horizon of any place.

To delineate the Orthographic Projection of the Circles of the Terrestrial Sphere upon the Plane of the Meridian of any Place. —With a radius according to the contemplated scale of the projection, describe the circle W N E S for the circumference of the primitive, and draw the vertical and horizontal diameters N S and W E, which will be the projections of a meridian perpendicular to the primitive, and of the equator, respectively. Take out from the line of sines the sines of the latitudes through which the parallels are to be drawn, and, reducing these sines to the radius of the primitive,*

* If the proportional compasses, described hereafter (page 60), be set in the proportion of the sine 90° on the line of sines to the radius

off these reduced distances both ways from the centre ı the line N S; and also both ways from the centre ı the line W E, for the sines of the angles which the meri-



s, to be drawn at the same ·vals as the parallels, make ı the meridian N S. Through divisions thus set off, upon line N S draw straight lines llel to W E, and such straight ı will be the projections of several parallels of latitude, ·h are to be numbered 0 to from the equator to either for the latitudes. With dis-es from the centre to the ıions set off upon W E as semi-minor axes, and the ınce from C to N or S, equal to radius of primitive, common semi-major axis, describe semi-ellipses, and they be the projections of the several meridians, which to be numbered either way from the first meridian he longitudes. In the figure the primitive coincides with ɔlane of the meridian of a place in 30° west longitude, 50° east longitude, the sum of these two being 180°, as ; always be the case.

ɔ delineate the Gnomonic Projection of the Circles of the estrial Sphere upon a Plane parallel to the Equator.—In case the meridians will all be projected into straight , making the same angles one with another that · originals do on the surface of the sphere; the pro-on of the pole will be the centre of the primitive, and projections of the parallels of latitude will be circles de-ed from the projection of the pole, as centre, with dis-es equal to the tangents of the respective colatitudes ced to the radius of the primitive. The parallel of 45° therefore, coincide with the circumference of the primi-the parallels of latitudes greater than 45° will lie in the primitive; and for latitudes less than 45° the llels will fall without the primitive, the radii of their ·ctions increasing as the latitude decreases, until the

e primitive, one pair of points will give, reduced to this radius, nes taken off by the other pair of points. The manner of taking the sector a sine to any radius will also be hereafter pointed out 47).

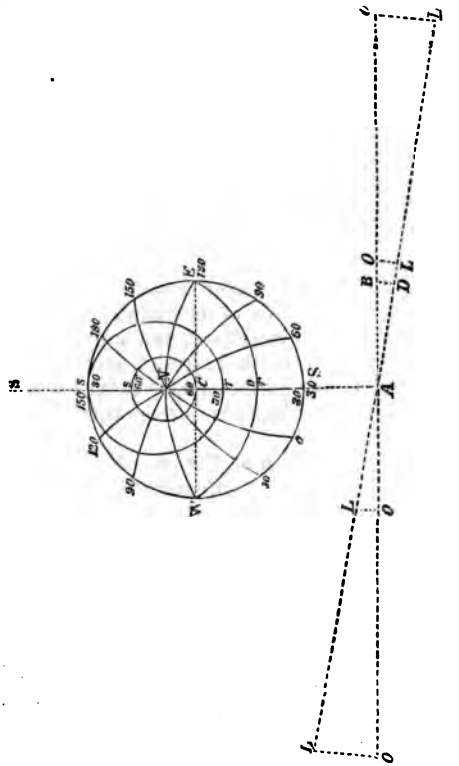
radius for projecting the equator becomes infinite. Describe, then, a circle for the primitive; draw straight lines radiating from its centre, and equally inclined one to another for the projections of equidistant meridians; and number them 0 to 180 both ways from the first meridian for the longitudes. With the tangents of the colatitudes, taken at intervals equal to the angle between two successive meridians, and reduced to the radius of the primitive, as distances, describe from the centre of the primitive concentric circles; and number them 90 to 45 from the pole to the primitive for the latitudes, continuing the graduation beyond for the lower latitudes.

The gnomic projection affords a good representation of the polar regions, but all places in latitudes lower than 60° appear

greatly distorted. The gnomonic projection enlarges the representations of places at a distance from the centre of projection.

To delineate the Stereographic Projection of the Circles of the Terrestrial Sphere upon the Horizon of any Place.—With radius determined upon describe a circle for the primitive, and draw its vertical and horizontal diameters, N S and W E, which will be the projections of the meridian of the place and of the prime vertical respectively. From the centre C set off upon the radius C S, produced, if necessary, the distance C A, equal to the tangent of the latitude of the place reduced to the

radius of the primitive; and with centre A and distance A W or A E describe the circle W N E, which will be the projection of the meridian at right angles to N S, the meridian of the place; and, consequently, N will be the projection of the pole. Through A draw the right line A B at right angles to



A C, and another line A D making any convenient angle with A B, and, setting off A B equal to the radius of the primitive, and A D equal to the sine of the colatitude, taken from the line of sines, join B D. Now take from the line of tangents the angles which the other meridians to be drawn are

to make with the meridian W N E, or the complements of the angles which they are to make with N S, and set them off both ways from A upon the line A D; through each of the divisions L, thus found, draw L O, parallels to B D, and we have at O the centres of the circles for describing the meridians.* With centres O and distances O N, describe the meridians, and number them 0 to 180, both ways, from the first meridian, for the longitudes. For a parallel through any given latitude, take the difference of the complement of the given latitude and of the colatitude of the place from the line of semitangents, and having reduced it to the radius of the primitive, set it off at *r* from C towards N for latitudes greater than the latitude of the place, and from C towards S for latitudes less than the latitude of the place:—again, take the sum of the complement of the given latitude and of the colatitude of the place from the line of semitangents, and set it off at *s* from C upon C N produced: then the circle described upon *r s* † as diameter will be the parallel required. Draw these parallels for intervals of latitude equal to the angles made by two successive meridians, and number them 90 to 0 from the pole N for the north latitudes, and again increasing from 0 on the other side of the equator for the south latitudes, if the place be in north latitude—or the converse if the place be in south latitude.

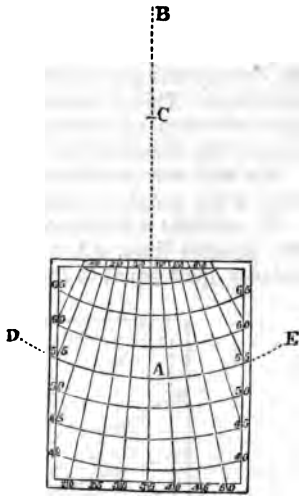
The practical application of the preceding methods of projection is usually confined to the representation of an entire hemisphere, or at least of a considerable portion of a sphere; but for laying down smaller portions of the sphere the method of development may be advantageously adopted. In this method the portion of the sphere to be represented is considered as coincident with a portion of a cone, touching the sphere in a circle which is the middle parallel of latitude of the country to be represented, and this portion of the cone when developed forms a portion of a sector of a circle.

To lay down the meridians and parallels of latitude for this development. 1. Take a straight line, B C A, for the middle meridian of the intended map, and divide it into equal parts, to represent degrees and minutes of latitude according to the

* The distance $A\,O = \frac{r \text{ cot. } L}{\text{cos. } l}$ where r represents the radius of the primitive, l the latitude of the place, and L the angle at which the meridian is inclined to the meridian of the place.

† Diameter of parallel $= r \text{ tan. } \frac{1}{2}(c - \delta) + r \text{ tan. } \frac{1}{2}(c + \delta)$ where $c =$ *colatitude of place,* and $\delta =$ colatitude of parallel.

determined upon for the map. 2. From one of these ions, A, which is conveniently situated to form the centre ıe map, set off from A to C the cotangent of the middle ıde, reduced to a radius equal to 57·3 of the divisions .ously marked off as de-
, or to 3,438 of those :ed off as minutes. 3. With a centre and radius C A, ıibe the arc D A E for the le parallel of latitude, and .e it into equal parts to re-
:nt degrees and minutes of tude, the lengths of these having, to the lengths of ıarts previously set off on meridian for degrees and .tes of latitude, the ratio e of middle latitude: ra-



4. With C as centre, de-
e concentric arcs, through divisions on C A, for the lels of latitude; and draw ght lines, radiating from ırough the divisions on ; for the meridians.

our figure the middle ıde is 55°; A B is equal to the length of 57·3°, or the .s of the sphere; A C is equal to the cotangent of 55, or angent of 35 reduced to this radius; and C, consequently, e centre for describing the parallels, and the radiating ; for the meridians.

drawing a map of small extent, it is usual to make all neridians and parallels of latitude straight lines; and to ; the extreme parallels, and the meridian passing through entre of the map, proportional to their real magnitude.

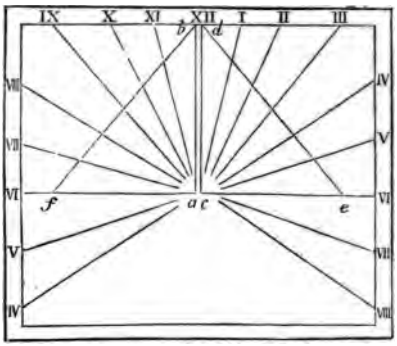
ıother and more exact method is to make the meridian ng through the centre of the map, and all the parallels itude, straight lines, as in the last method. Then all the ees on each of the parallels are made proportional to magnitude, and the lines passing through the corre-ding points of division on the parallels will represent the dians. These will be curved lines, and not straight, as ıe last method. This is usually called *Flamstead's Pro-on, as it was first* used by that astronomer in constructing

his "Celestial Atlas;" and it is extremely useful in geographical maps for countries lying on both sides of the equator.

A considerable improvement of this method, for countries of large extent, is to represent all the parallels of latitude by concentric circles, according to the principles of the conical development; and then to lay off the degrees on each parallel, proportional to their magnitude,* and draw lines through the corresponding divisions of these parallels to represent the meridians. This delineation, perhaps, will give the different parts of a map of some extent in as nearly their due proportions as the nature of the case will admit.

We will now briefly explain the manner of constructing some of the simplest dials by means of the dialling scales.

To construct a Horizontal Dial.—Draw on your dial plate two parallel lines, *a b*, *c d*, as a double meridian line, at a distance apart equal to the thickness of the intended style, or

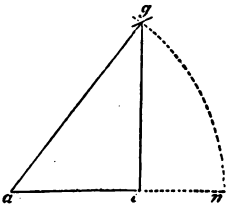


gnomon. Intersect them at right angles by another line, *e f*, called the six-o'clock line. From the scale of latitudes take the latitude of the place with the compasses, and set that extent from *c* to *e* and from *a* to *f* on the six-o'clock line, and then, taking the whole of six hours between the points of the compasses from the scale, with this extent set one foot in the point *e*, and with the other intersect the meridian line *c d* at *d*. Do the same from *f* to *b*, and draw the right lines *e d* and *f b*, which are of the same lengths as the scale of hours. Place one foot of the compasses on the beginning of the scale,

* That is, the degrees on each parallel must have to a degree of latitude the ratio of radius : cosine of the latitude of the parallel.

and, extending the other to any hour on the scale, lay these extents off from *d* to *e* for the afternoon hours, and from *b* to *f* for the forenoon. In the same manner the quarters or minutes may be laid down, if required. The edge of a ruler being now placed on the point *c*, draw the first five afternoon hours from that point through the marks on the line *d e*, and continue the lines of IV and V through the centre *c* to the other side of the dial for the like hours of the morning. Lastly, lay a ruler on the point *a*, and draw the last five forenoon hours through the marks on the line *f b*, continuing the hour lines of VII and VIII through the centre *a* to the outer side of the dial for the evening hours, and figure the hours to the respective lines.

To make the Gnomon.—From the line of chords, always placed on the same dialling scale, take the extent of 60°, and describe from the centre *a* the arc *g n*. Then with the extent of the latitude of the place, suppose London, 51½°, taken from the same line of chords, set one foot in *n*, and cross the arc with the other at *g*. From the centre at *a* draw the line *a g* for the axis of the gnomon *a g i*, and from *g* let fall the perpendicular *g i* upon the horizontal meridian line *a n*, and there will be formed a triangle *a g i*. A plate or triangular frame similar to this triangle, and of the thickness of the interval of the parallel lines *a c* and *b d*, being now made and set upright between them, touching at *a* and *b*, its hypothenuse or axis *a g* will be parallel to the axis of the earth when the dial is fixed truly, and will cast its shadow on the hour of the day.



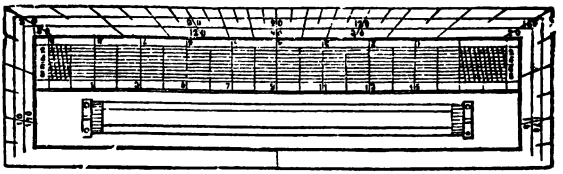
To make an erect South Dial.—Take the complement of the latitude of the place, which for London is 90° less 51½ = 38½, from the scale of latitudes, and proceed in all other respects for the hour lines as above for the horizontal dial; only reversing the hours, and limiting them to the VII, and for the gnomon making the angle of the style's height equal to the colatitude 38½.

To construct an East or West Dial.—Draw the two meridian lines as before, and intersect them at right angles by another line, upon which set off, from the meridian lines, the tangents of 15°, 30°, 45°, &c., for every 15°, reduced to a radius equal to the intended height of the style. The hour

lines are to be drawn through the divisions thus marked, parallel to the meridian lines, and the meridian lines themselves are six-o'clock hour lines. The gnomon is a plate in the form of a parallelogram, the breadth of which forms the height of the style or gnomon, and must be equal to the radius to which the tangents have been set off on the dial plate. It is set up between the meridian lines, perpendicular to the dial plate; and the dial is set up so that the meridian lines, and consequently the edge of the gnomon, may *be parallel* to the earth's axis. As the sun only shines on the dial during half the day, if the dial fronts the east, it points out the time from sunrise to noon, or, if the dial fronts the west, from noon to night.

THE PROTRACTOR, OR PLAIN SCALE.

One of these instruments is represented in the annexed figure, being such a one as is usually supplied with a pocket case of instruments. It is made of ivory, six inches long, and one inch and three-quarters broad. On the face of the instrument represented in the engraving, a protractor is formed round three of its edges for readily setting off angles. In using this protractor, the fourth edge or base is to be made to coincide with the line from which the angle is to be set off, and the stroke in the middle of the base with the point in this line at which the angle is to be set off; a mark is then to be made with the pricking point at the point of the paper which coincides with the stroke on the protractor marked with the number of degrees in the angle required to be drawn; and, the protractor being now removed, a straight line is to be



drawn through the given point in the given line and the point thus pricked off. The instrument has on the same face the two diagonal scales already described (p. 24), and on the opposite face scales of equal parts and several of the protract-

ing scales already described (pp. 26—30), according to the purposes to which the scale is to be applied. The plain scale is sometimes fitted with roller, as represented in our engraving, making it at the same time a convenient small parallel ruler.

THE MILITARY PROTRACTOR.

The distinguishing feature of this instrument is a series of equidistant parallel lines across it, forming a scale of equal parts. They are ruled perpendicular to the longer sides of the instrument, the zero of the scale leading from the centre of the base to 90° on the protractor. These lines present a peculiar advantage for making sketches of field-work, the readings of which have been taken with the prismatic compass, as they may be made to represent lines perpendicular to the magnetic meridian, or magnetic east and west lines. The paper on which the sketch is to be made is also ruled with a series of lines parallel to each other, but at unequal distances, which may also be taken to represent lines from east to west, so that the protractor can be laid upon it, and some one of the lines ruled across it be made to coincide with one of the ruled lines upon the paper, at the same time that the zero of the scale is kept in coincidence with any desired point, and, the base of the scale when in this position coinciding with a magnetic meridian, the angular bearings of other points from this one, as taken by the compass, can be at once pricked off.

For the purpose of setting off the angles taken with the prismatic compass, it is a matter of indifference what scale the equidistant parallel lines may represent, or at what distances the lines may be ruled on the paper, provided that these be so arranged, that some one of the lines on the scale can always be made coincident with one of the lines on the paper, at whatever point on the latter the zero of the scale may be placed. By making, however, the scale such a one as has been found convenient for military sketches, it may be used for pricking off the distances at once, as well as for setting of the angles. The scale selected, therefore, is 4 inches to a mile; and 4 inches are divided into 176 parts, or each inch into 44 parts: the parallel lines are then ruled through each division, the zero line and every tenth line on either side of it being red, and the intermediate lines black; thus the distance between

but if not, it must be taken from an independent scale, and set off on a line ruled from A to B.

If the distance be measured in paces instead of yards, the

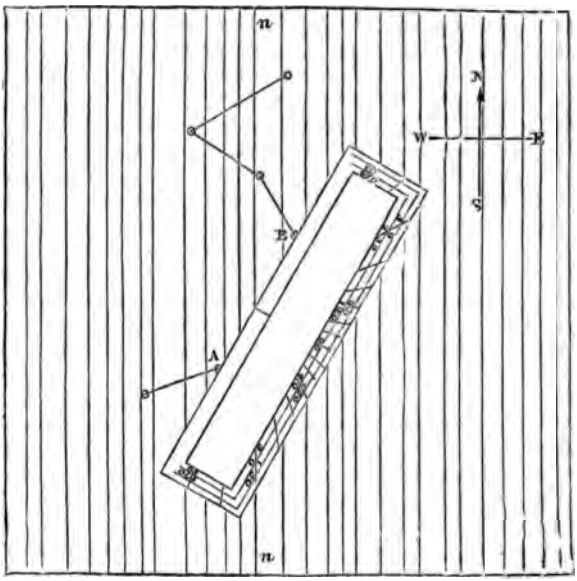


Fig. 2.

same scale may be used for laying them off; but the plan will now be one of as many paces to the inch, as the scale used is of yards to the inch.

THE SECTOR.

This instrument may well be called a universal scale. By its aid all questions in proportion may be solved; lines may be divided either equally or unequally into any number of parts that may be desired; the angular functions, viz., chords, sines, tangents, &c., may be set off or measured to any radius whatever; plans and drawings may be reduced or enlarged in any required proportion; and, in short, every operation in geometrical drawing may be performed by the aid of this instrument and the compasses only.

The name sector is derived from the tenth definition of the third Book of Euclid, in which this name is given to the figure contained by two radii of a circle, and the circumference between them. The instrument consists of two equal rulers, called legs, which represent the two radii, movable about the centre of a joint, which centre represents the centre of the circle. The legs can consequently be opened so as to contain any angle whatever, or completely opened out until their edges come into the same straight line.

Sectors are made of different sizes, and their length is usually denominated from that of the legs when shut together. Thus, a sector of 6 inches, such as is supplied in the common pocket cases of instruments, forms a rule of 12 inches when opened; and this circumstance is taken advantage of, by filling up the spaces not occupied by the sectorial lines with such lines as it is most important to lay down upon a greater length than the 6-inch plain scale will admit. Among these the most usual are (1) the lines of logarithmic numbers, sines, and tangents, described in Part II.; (2) a scale of 12 inches, in which each inch is divided into ten equal parts; and (3) a foot divided into ten equal primary divisions, each of which is subdivided into ten equal parts, so that the whole is divided into 100 equal parts. The last-mentioned is called the decimal scale, and is placed on the edge of the instrument.

The *sectoral lines* proceed in pairs from the centre, one line of each pair on either leg, and are, upon one face of the instrument, a pair of scales of equal parts, called the *line of lines*, and marked L; a pair of lines of chords, marked C; a pair of lines of secants, marked S; a pair of lines of polygons, marked POL. Upon the other face, the sectoral lines are—a pair of lines of sines, marked S; a pair of lines of tangents up to 45°, marked T; and a second line of tangents to a lesser radius, extending from 45° to 75°.

Each pair of sectoral lines, except the line of polygons,

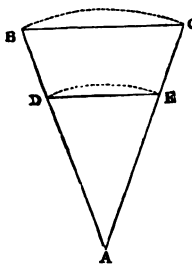
should be so adjusted as to make equal angles at the centre, so that the distances from the centre to the corresponding divisions of any pair of lines, and the transverse distance between these divisions, may always form similar triangles. On many instruments, however, the pairs of lines of secants, and of tangents from 45° to 75°, make angles at the centre equal to one another, but unequal to the angle made by all the other pairs of lines.

The solution of questions on the sector is said to be *simple* when the work is begun and ended upon the same pair of lines; *compound*, when the operation is begun upon one pair of lines and finished upon another.

In a compound solution the two pairs of lines used must make equal angles at the centre, and, consequently, in the exceptional case mentioned above, the lines of secants and of tangents above 45° cannot be used in connection with the other sectoral lines.*

When a measure is taken on any of the sectoral lines beginning at the centre, it is called a *lateral* distance; but when a measure is taken from any point on one line to its corresponding point on the line of the same denomination on the other leg, it is called a *transverse* or *parallel* distance.

The divisions of each sectoral line are contained within three parallel lines, *the innermost* being the line on which the points of the compasses are to be placed, because this is the only line of the three which goes to the centre, and is therefore the sectoral line.



On the principle of the Use of the Sectoral Lines.—1st. *In the Case of a Simple Solution.*—Let the lines A B, A C represent a pair of sectoral lines, and B C, D E any two transverse distances taken on this pair of lines; then, from the construction of the instrument, we

* Since, however, secant : rad. :: rad. : cosine :
and tangent : rad. :: rad. : cotangent;
the line of sines may be used with the other sectoral lines in place of the line of secants, and the line of tangents less than 45° in place of the line of tangents greater than 45°, the complements of the angles being taken upon these lines, in either case, instead of the angles themselves. See page 51.

have A B equal to A C, and A D equal to A E, so that A B : A C :: A D : A E, and the triangles A B C and A D E have the angle at A common, and the sides about this common angle proportional; they are, therefore, similar (Euc. vi. prop. 6) and—

A B : B C :: A D : D E.

In the case of a compound solution, the angles at A are equal, but not common, and the reasoning is, in all other respects, exactly the same.

USES OF THE LINE OF LINES.

To find a Fourth Proportional to Three given Lines.—Set off from the centre a lateral distance equal to the first term, and open the sector till the transverse distance at the division thus found, expressing the first term, is equal to the second term; again, extend to a point whose lateral distance from the centre is equal to the third term, and the transverse distance at this point will be the fourth term required.

If the legs of the sector will not open far enough to make the lateral distance of the second term a transverse distance at the division expressing the first term, take any aliquot part of the second term which can conveniently be made such transverse distance, and the transverse distance at the third term will be the same aliquot part of the fourth proportional required.

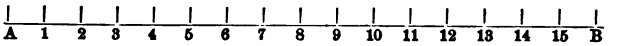
A third proportional to two given lines is found by taking a third line equal to the second, and finding the fourth proportional to the three lines.

Example.—To find a fourth proportional to the numbers 2, 5, and 10. Open the sector till the lateral distance of the second term 5 becomes the transverse distance at 2, the first term; then the transverse distance at 10 will extend, as a lateral distance, from the centre to 25, the fourth proportional required.

To bisect a given Straight Line.—Take the extent of the line in the compasses, and open the sector till this extent is a transverse between 10 and 10 on the line of lines: then the transverse distance from 5 to 5 on the same pair of sectoral lines gives the half of the line, and this extent set off from either end will bisect it.

To divide a Straight Line into any Number of equal Parts.—1. When the number of parts is a power of 2, the opera-

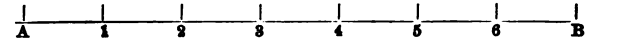
tions are best performed by continual bisection. Thus, let it be required to divide the line A B into sixteen equal parts. (1.) Make A B a tranverse distance between 10 and 10 on the



line of lines; then take off the transverse distance of 5 and 5 and set it off from A or* B to 8, and A B will be divided into two equal parts at the division 8. (2.) Make A 8 a transverse distance at 10, and then the transverse distance at 5, set off from A or* 8 at 4, and from B or* 8 at 12, will divide the line into four equal parts at the divisions 4, 8, and 12. (3.) Make the extent A 4 a transverse distance at 10, and the transverse distance at 5 will again bisect each of the parts last set off, and divide the whole line into eight equal parts at the divisions 2, 4, 6, 8, 10, 12, and 14. Each of these may be again bisected by taking the transverse distance at 2½ or 2·5, that is, at the middle division between the 2 and the 3 upon the line of lines, and the line will be divided as required.

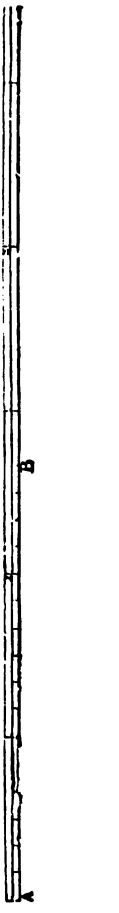
When the divisions become smaller than can be conveniently bisected by the method just explained, the operation may still be continued to any required extent by taking the extent of an odd number of the divisions already obtained as the transverse distance of 10 and 10, and setting off the half of this extent, or the transverse distance at 5, from the several divisions already obtained. Thus, in the preceding example, by making the extent of three of the divisions, or five, or seven, a transverse distance at 10, the transverse distance at 5, set off from the several divisions already obtained, will divide A B into 32 equal parts.

2. When the number of parts is not a power of 2, the operations cannot all be performed by bisections; but still, by a judicious selection of the parts into which the line is first divided, many of the after-operations may be performed by bisections. *Example.*—Let it be required to divide the line A B into seven equal parts. (1.) Make the whole extent,



* Greater accuracy is obtained by setting off the distance from both ends of the extent to be bisected, and then, in case the two points so found do not accurately coincide, taking the middle point between them, as near as the eye can judge, for the true point of bisection.

A B, a transverse distance between 7 and 7 on the line of lines; then take off the transverse distance of 4 and 4, and set it off from A and B to 4 and 3. (2.) Make this extent from A to 4 a transverse distance at 10; then the transverse distance at 5 bisects A 4 and 3 B in 2 and 5; set off from 3, gives 1, and from 4 gives 6; and thus the line A B is divided into seven equal parts as required.



To open the Sector so that the Line of Lines may answer for any required Scale of equal Parts.—Take one inch in the compasses, and open the sector till this extent becomes a transverse distance at the division indicating the number of parts in an inch of the required scale; or, if there be not an integral number of parts in one inch, it will be better to take such a number of inches as will contain an integral number of parts, and make the extent of this number of inches, if it be not too great, a transverse distance at the division indicating the number of parts of the required scale in this extent.

Example.—To adjust the Sector as a Scale of One Inch to Four Chains.—Make one inch the transverse distance of 4 and 4; then the transverse distances of the other corresponding divisions and subdivisions will represent the number of chains and links indicated by these divisions: thus, the transverse distance from 3 to 3 will represent three chains; the transverse distance at 4·7, or the seventh principal subdivision after the primary division marked 4, will represent 4 chains 70 links, and so on.

To construct a Scale of Feet and Inches in such a manner that an extent of Three Inches shall represent Twenty Inches.—1. Make three inches a transverse distance between 10 and 10, and the transverse distance of 8 and 8 will represent 16 inches. 2. Set off this extent from A to B, divide it by continual bisection into 16 equal parts, and place permanent strokes to mark the first 12 of these divisions, which will represent inches. 3. Place the figure 1 at the twelfth stroke, and set off again the extent of the whole 12 parts, from 1 to 2, 2 to 3, &c., to represent the feet.

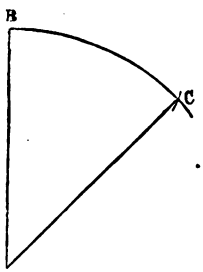
As an example of the Use of the Line of Lines in reducing Drawings, let it be required to reduce the Linear Dimensions of a

Drawing in the Proportion of 8 *to* 5.—1. Take in the compasses the distance between two points of the drawing, and make it a transverse distance at 8 and 8; then the transverse distance of 5 and 5 will be the distance between the two corresponding points of the copy. 2. These two points having been laid down, make the distance between one of them and a third point a tranverse distance at 8, and with the transverse distance at 5 describe, from that point as centre, a small arc. 3. Repeat the operation with the other point, and the intersection of the two small arcs will give the required position of the third point in the copy. In the same manner all the other points of the reduced copy may be set off, each one from two points previously laid down.

LINE OF CHORDS.

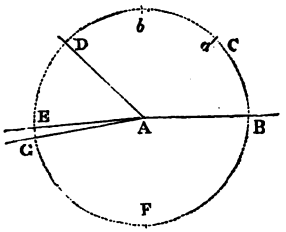
The double scales of chords upon the sector are more generally useful than the single line of chords laid down on the plain scale; for, on the sector, the radius with which the arc is to be described may be of any length between the transverse distance of 60 and 60 when the legs are closed, and that of the transverse of 60 and 60 when the legs are opened as far as the instrument will admit of; but, with the chords on the plain scale, the arc described must be always of the same radius.

To protract or lay down a right-lined Angle B A C, *which shall contain a given Number of Degrees, suppose* 46°.—*Case* 1. When the angle contains less than 60°, make the transverse distance of 60 and 60 equal to the length of the radius of the circle, and with that opening describe the arc B C. Take the transverse distance of the given degrees 46, and lay this distance on the arc from the point B to C. From the centre A of the arc draw two lines A C, A B, each passing through one extremity of the distance B C laid on the arc, and these two lines will contain the angle required. *Case* 2. When the angle contains more than 60°. Suppose, for example, we wish to form an angle containing 138°. Describe the arc B C D, and make the transverse distance of 60 and 60 equal the radius as before. Take the



transverse distance of $\frac{1}{2}$ or $\frac{1}{3}$, &c., of the given number of degrees, and lay this distance on the arc twice or thrice, as from B to *a*, *a* to *b*, and from *b* to D. Draw two lines connecting B to A, and A to D, and they will form the angle required.

When the required angle contains less than 5°, suppose $3\frac{1}{2}$, it will be better to proceed thus. With the given radius, and from the centre A, describe the arc D G; and from some point, D, lay off the chord of 60°, which suppose to give the point G, and also from the same point D lay off in the same direction the chord of $56\frac{1}{2}$° (= 60° — $3\frac{1}{2}$°), which would give the point E. Then through these two points E and G, draw lines to the point A, and they will represent the angle of $3\frac{1}{2}$° as required.



From what has been said about the protracting of an angle to contain a given number of degrees, it will easily be seen how to find the degrees (or measure) of an angle already laid down.

LINE OF POLYGONS.

The line of polygons is chiefly useful for the ready division of the circumference of a circle into any number of equal parts from 4 to 12; that is, as a ready means to inscribe regular polygons of any given number of sides, from 4 to 12, within a given circle; to do which, set off the radius of the given circle (which is always equal to the side of an inscribed hexagon) as the transverse distance of 6 and 6 upon the line of polygons. Then the transverse distance of 4 and 4 will be the side of a square; the transverse distance between 5 and 5, the side of a pentagon; between 7 and 7, the side of a heptagon; between 8 and 8, the side of an octagon; between 9 and 9, the side of a nonagon, &c., all of which is too plain to require an example.

If it be required to form a polygon, upon a given right line, set off the extent of the given line, as a transverse distance, between the points upon the line of polygons answering to the number of sides of which the polygon is to consist; as for a pentagon between 5 and 5; or for an octagon between 8 and 8: then the transverse distance between 6 and 6

will be the radius of a circle whose circumference would be divided by the given line into the number of sides required.

The line of polygons may likewise be used in describing, upon a given line, an isosceles triangle, whose angles at the base are each double that at the vertex. For, taking the given line between the compasses, open the sector till that extent becomes the transverse distance of 10 and 10, then the transverse distance of 6 and 6 will be the length of each of the two equal sides of the isosceles triangle.

All regular polygons whose number of sides will exactly divide 360 (the number of degrees into which all circles are supposed to be divided) without a remainder may likewise be set off upon the circumference of a circle by the line of chords. Thus, take the radius of the circle between the compasses, and open the sector till that extent becomes the transverse distance between 60 and 60 upon the line of chords; then, having divided 360 by the required number of sides, the transverse distance between the numbers of the quotient will be the side of the polygon required. Thus, for an octagon, take the distance between 45 and 45; and for a polygon of 36 sides take the distance between 10 and 10, &c.

LINES OF SINES, TANGENTS, AND SECANTS.

Given the Radius of a Circle (suppose equal to two inches); required the Sine and Tangent of 28° 30′ *to that Radius.*—Open the sector so that the transverse distance of 90 and 90 on the sines, or of 45 and 45 on the tangents, may be equal to the given radius, viz., two inches; then will the transverse distance of 28° 30′, taken from the sines, be the length of that sine to the given radius, or, if taken from the tangents, will be the length of that tangent to the given radius.

But if the Secant of 28° 30′ *is required,* make the given radius of two inches a transverse distance of 0 and 0 at the beginning of the line of secants, and then take the transverse distance of the degrees wanted, viz., 28° 30′.

A Tangent greater than 45° (*suppose* 60°) *is thus found:*—Make the given radius, suppose two inches, a transverse distance to 45 and 45 at the beginning of the line of upper tangents, and then the required degrees (60) may be taken from the scale.

The tangent to a given radius of any number of degrees

greater than 45° can also be taken from the line of lower tangents, if the radius can be made a transverse distance to the complement of those degrees on this line (see note, p. 44).

Example.—To find the tangent of 78° to a radius of two inches. Make two inches a transverse distance at 12 on the lower tangents, then the transverse distance of 45 will be the tangent of 78°.

In like manner the secant of any number of degrees may be taken from the sines, if the radius of the circle can be made a transverse distance to the complement of those degrees upon this line. Thus, making two inches a transverse distance to the sine of 12°, the transverse distance of 90 and 90 will be the secant of 78°.

To find, by means of the lower tangents and sines, the degrees answering to a given line, greater than a given radius which expresses the length of a tangent or secant to this radius. For a tangent, make the given line a transverse distance at 45 on the lower tangents; then take the extent of the given radius, and apply it to the lower tangents; and the complement of the degrees at which it becomes a transverse distance will be the number of degrees required. For a secant make the given line a transverse distance at 90 on the sines; then the extent of the radius will be a transverse distance at the complement of the number of degrees required.

Given the Length of the Sine, Tangent, or Secant of any Degrees, to find the Length of the Radius to that Sine, Tangent, or Secant.—Make the given length a transverse distance to its given degrees on its respective scale. Then,

If a sine If a tangent under 45° If a tangent above 45° If a secant	}	the transverse distance of	{ 90 and 90 on the sines 45 and 45 on the tangents 45 and 45 on the upper tangents 0 and 0 on the secants	} will be the radius sought.

To find the Length of a versed Sine to a given Number of Degrees and a given Radius.—1. Make the transverse distance of 90 and 90 on the sines equal to the given radius. 2. Take the transverse distance of the sine of the complement of the given number of degrees. 3. If the given number of degrees be less than 90, subtract the distance just taken, viz., the sine of the complement, from the radius, and the remainder will be the versed sine: but, if the given number of degrees is more than 90, add the complement of the sine to the radius, and the sum will be the versed sine.

To open the legs of a Sector, so that the corresponding double Scales of Lines, Chords, Sines, and Tangents may make each a Right Angle.—On the line of lines make the lateral distance 10, a transverse distance between 8 on one leg and 6 on the other leg.

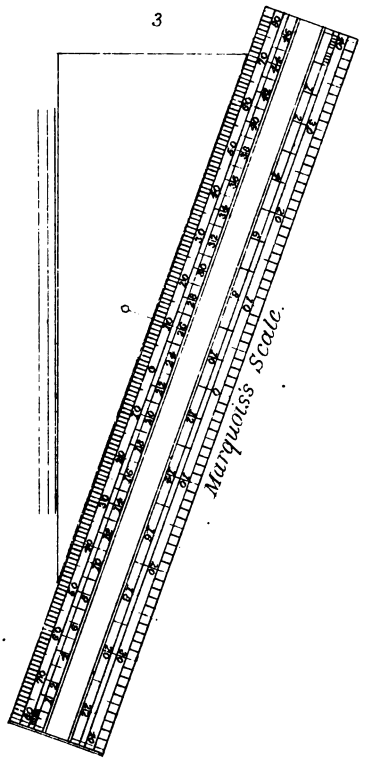
On the line of sines make the lateral distance 90, a transverse distance from 45 to 45; or from 40 to 50; or from 30 to 60; or from any degree to its complement.

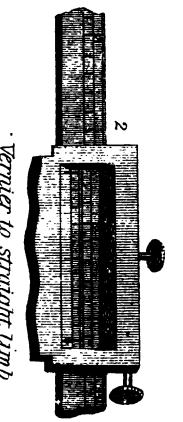
On the line of sines make the lateral distance of 45 a transverse distance between 30 and 30.

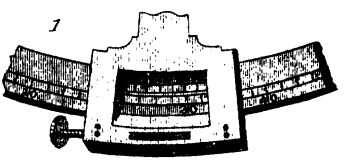
MARQUOIS'S SCALES. (Plate II. Fig. 3.)

These scales consist of a right-angled triangle, of which the hypothenuse or longest side is three times the length of the shortest, and two rectangular rules. Our figure, which is drawn one-third the actual size of the instruments from which it is taken, represents the triangle and one of the rules, as being used to draw a series of parallel lines. Either rule is one foot long, and has, parallel to each of its edges, two scales, one placed close to the edge and the other immediately within this, the outer being termed the artificial, and the inner the natural scale. The divisions upon the outer scale are three times the length of those upon the inner scale, so as to bear the same proportion to each other that the longest side of the triangle bears to the shortest. Each inner, or natural scale, is, in fact, a simply-divided scale of equal parts (see p. 22), having the primary divisions numbered from the left hand to the right throughout the whole extent of the rule. The first primary division on the left hand is subdivided into ten equal parts, and the number of these subdivisions in an inch is marked underneath the scale, and gives it its name. On one of the pair of Marquois's scales now before us, we have, on one face, scales of 30 and 60, on the obverse scales of 25 and 50, and on the other we have on one face scales of 35 and 45, and on the obverse scales of 20 and 40. In the artificial scales the zero point is placed in the middle of the edge of the rule, and the primary divisions are numbered both ways from this point to the two ends of the rule, and are every one subdivided into ten equal parts, each of which is, consequently, three times the length of a subdivision of the corresponding natural scale.

Plate II.







Vernier to arched limb.

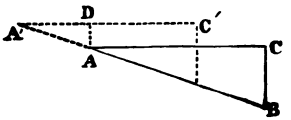
The triangle has a short line drawn perpendicular to the hypothenuse near the middle of it, to serve as an index or pointer; and the longest of the other two sides has a sloped edge.

To draw a Line parallel to a given Line, at a given Distance from it.—1. Having applied the given distance to the one of the natural scales which is found to measure it most conveniently, place the triangle with its sloped edge coincident with the given line, or rather, at such small distance from it that the pen or pencil passes directly over it when drawn along this edge. 2. Set the rule closely against the hypothenuse, making the zero point of the corresponding artificial scale coincide with the index upon the triangle. 3. Move the triangle along the rule to the left or right, according as the required line is to be above or below the given line, until the index coincides with the division or subdivision corresponding to the number of divisions or subdivisions of the natural scale, which measures the given distance; and the line drawn along the sloped edge in its new position will be the line required.*

NOTE.—The natural scale may be used advantageously in setting off the distances in a drawing, and the corresponding artificial scale in drawing parallels at required distances.

To draw a Line perpendicular to a given Line from a given Point in it.—1. Make the shortest side of the triangle coincide with the given line, and apply the rule closely against the hypothenuse. 2. Slide the triangle along the rule until a line drawn along the sloped edge passes through the given point, and the line so drawn will be the line required.

* If A B C represent the triangle in its new position, and the dotted



lines represent its original position, we have, by similar triangles, A B C, A' A D.

$$\text{A D} : \text{A A}' :: \text{B C} : \text{B A}$$
$$:: 1 : 3;$$

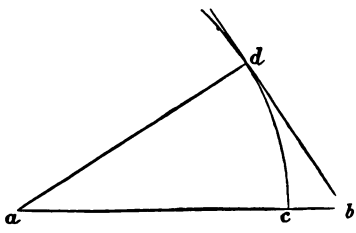
and therefore A D contains as many divisions of the natural as A A contains of the artificial scale.

The advantages of Marquois's scales are: 1st, that the sight is greatly assisted by the divisions on the artificial scale being so much larger than those of the natural scale to which the drawing is constructed; 2nd, that any error in the setting of the index produces an error of but one-third the amount in the drawing.

If the triangle be accurately constructed, these scales may be advantageously used for dividing lines with accuracy and despatch; our figure of the Marquois's scales was drawn by the aid of themselves alone.

We proceed to explain a method which we have found to answer well for dividing lines with accuracy and despatch, and which is altogether independent of any error in the construction of the triangle.

Let *a b* represent the line to be divided into any number, *n*, of equal parts; select one of the natural scales, of which *n* divisions or some multiple *p n* of *n* divisions, are nearly equal to *a b*, but less than it; then setting the sloped edge of the triangle perpendicular to *a b*, so that a line drawn along it passes through *a*, place the rule closely against the hypothenuse, making a division of the artificial scale corresponding to the selected natural scale, coincide with the index upon the triangle; and, moving the triangle along the rule to the right, until the index coincides with the *p n*th division from that to which it was set, draw a line along the sloped edge intersecting *a b* in *c*. Upon *a b* as hypothenuse describe the right-angled triangle *a b d*, having the side *a d* equal to *a c*, and place the sloped edge of the triangle to coincide with *b d*, which touches the circular arc *c d* described from the centre *a*, and is consequently perpendicular to *a d*; then, sliding the triangle along the rule to the right or left, and drawing a line as the index comes into contact with every *p*th division of the artificial scale, the line *a b* will be divided as required.



THE VERNIER.

Before proceeding to the description of the circular protractor, we will describe a subsidiary instrument called the

vernier, which is applied to all instruments in which great accuracy of measurement is required, in order to measure portions of the space between the equidistant divisions of a graduated scale.

This ingenious little instrument is so constructed as to slide evenly along the graduated limb of an instrument, and enables us to measure distances, or read off observations, with remarkable nicety. It is in fact a scale in which the divisions differ slightly in length from those of the graduated limb to which it is applied. The divisions are usually shorter than those upon the limb to which it is attached, the length of the graduated scale of the vernier being exactly equal to the length of a certain number $(n-1)$ of the divisions upon the limb, and the number (n) of divisions upon the vernier being one more than the number upon the same length of the limb.

Let, then, L represent the length of a division upon the limb, and V, the length of a division upon the vernier:

so that $(n-1)\,\mathrm{L} = n\,\mathrm{V}$;

$$\text{and therefore } \mathrm{L} - \mathrm{V} = \mathrm{L} - \frac{n-1}{n}\mathrm{L} = \frac{1}{n}\mathrm{L};$$

or the defect of a division upon the vernier from a division upon the limb is equal to the nth part of a division upon the limb, n being the number of divisions upon the vernier.

If n divisions of the vernier were equal to $(n+1)$ divisions of the limb, or $(n+1)\,\mathrm{L} = n\,\mathrm{V}$,

$$\text{then would } \mathrm{V} - \mathrm{L} = \frac{n+1}{n}\mathrm{L} - \mathrm{L} = \frac{1}{n}\mathrm{L};$$

or the excess of a division upon the vernier above a division upon the limb would be equal to the nth part of a division upon the limb. With this arrangement, however, we should have the vernier reading backwards, an arrangement which is the most convenient in the case of the mountain barometer.

In fig. 1, six divisions of the vernier are equal to five divisions of the limb, and, consequently, the above defect, or L — V, is equal to a sixth part of a division upon the limb, or to 20′, since a division of the limb is equal to 2°.

In fig. 2, ten divisions of the vernier are equal to nine divisions of the limb, and, consequently, L — V is equal to a tenth part of a division upon the limb, or to the hundredth

part of an inch, a division of the limb being equal to the tenth part of an inch.

In reading off we must first look to the lozenge, as pointing out the exact place upon the limb at which the required measurement is indicated. If, then, the stroke upon the vernier at the lozenge exactly coincides with a stroke upon the limb, the reading at this stroke gives the measurement required; but if the stroke at the lozenge be a distance beyond a stroke upon the limb, then will this distance be equal to once, or twice, or thrice, &c., the difference of a division upon the limb and upon the vernier, according as the stroke at the end of the first, or second, or third, &c., division upon the vernier coincides with a stroke upon the limb.

In Fig. 1 the stroke upon the vernier at the lozenge falls beyond the stroke indicating 22° upon the limb, and the stroke at the end of the second division upon the vernier coincides with a stroke upon the limb; the reading therefore is 22° 40′.

In Fig. 2 the stroke upon the vernier at the lozenge falls beyond the stroke indicating one inch and three-tenths upon the limb, and the stroke at the end of the sixth division upon the vernier coincides with a stroke upon the limb: the reading, therefore, is 1·36 inches, or one inch three-tenths and six hundredths.

The limbs of the best sextants are now divided at every ten minutes, and 59 of these parts are made equal to 60 divisions of their verniers. In this case

$$\text{L} - \text{V} = \frac{\text{L}}{60} = \frac{10'}{60'} = 10'';$$

so that these instruments can be read off by the aid of their verniers to an accuracy of 10 seconds. The verniers occupy on the limbs spaces equal to 9° 50′.*

The limbs of circular protractors and of small theodolites are generally divided at every 30 minutes, and 29 of these

* That is, according to the graduation of the instrument; but, as the angles observed by a sextant are double the angles moved over by the index, the limb of the instrument is graduated, as though it were double the size, so that the verniers really occupy an arc of 4° 55′ only.

parts are made equal to 30 divisions of their verniers, which therefore enables us to read off to an accuracy of $\frac{30'}{30}$, or 1'.

In the mountain barometer the scale being divided into 20ths of an inch, 10 divisions of the vernier are made equal to 11 of these parts, which therefore enables us to read off to an accuracy of the 200th of an inch.

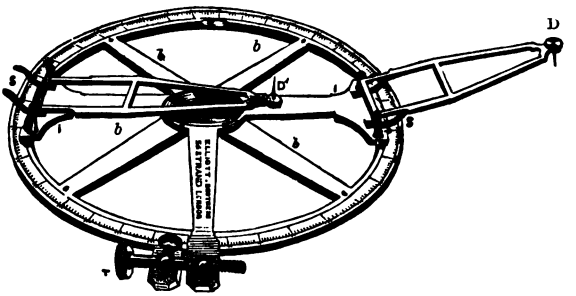
In plotting a survey due regard must be had to both accuracy and despatch, and we should aim to lay down the various points observed with an accuracy proportionate to the accuracy of the survey itself. To this end the principal points should be laid down by setting off with the beam compasses the computed sides of the triangles, the angles of which have been accurately observed with the large theodolite; and the direction of the meridian is to be laid down from an observation of the angle which it makes with a side of one of these triangles, by means of the computed chords,* which chord is also to be set off with the beam compasses.

THE CIRCULAR PROTRACTOR.

The principal points having thus been laid down, the boundaries may be put in by first laying down upon the paper a large circular protractor. This protractor may be pricked off by means of the circular metallic protractor represented in the accompanying figure, and the lines can then be transferred to any part of the paper by means of a large ruler and triangle, or by any parallel ruler. The circular protractor is a complete graduated circle, connected with its centre by four radial bars, *b b b b*. The centre is left open, and surrounded by a concentric ring, or collar, which carries two indices, I, I, with verniers working quite round the circumference of the protractor, and subdividing the primary divisions on the protractor to single minutes, and by estimation to 30 seconds. To the index bars are attached the branches, D, D', carrying at their extremities fine steel prickers, whose points are kept above the surface of the paper by springs placed under their supports, which give way when the branches are pressed downwards,

* If a table of chords be not at hand, take out the sine of half the angle from a table of natural sines, and reckoning the first figure as integral, this will be the chord of the whole angle to radius 5, or, reckoning the first two figures integral, it will be the chord to radius 50.

and allow the points to make the necessary punctures in the paper. The branches, D, D', are attached to the index bars, I, I, with a joint which admits of their being folded backwards over the instrument when not in use, and for packing in its case. The centre of the instrument is represented by the intersection of two lines drawn at right angles to each other on a piece of plate glass, which enables the person using it to place it so that the centre, or intersection of the cross lines, may coincide with any given point on the plan. If the instrument is in correct order, a line connecting the fine pricking points with each other would pass through the centre of the instrument, as denoted by the before-mentioned intersection

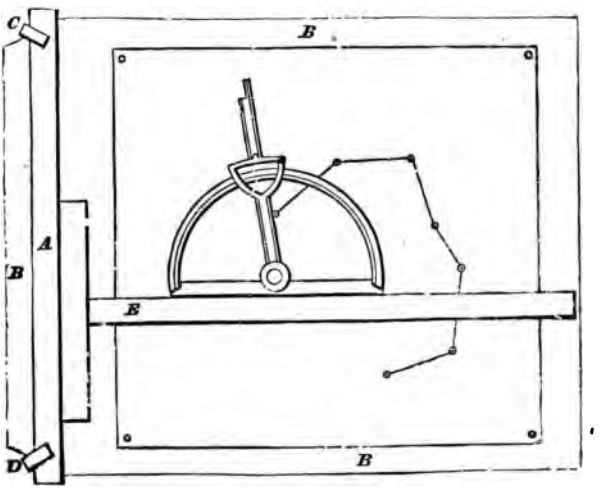


of the cross lines upon the glass, which, it may be observed, are drawn so nearly level with the under surface of the instrument as to do away with any serious amount of parallax, when setting the instrument over a point from which any angular lines are intended to be drawn. In using this instrument one of the verniers, called the forward-angle vernier, should first be set to zero (or the division marked 360°) on the divided limb, and the other, called the back-angle vernier, at the division marked 180°; and it should then be placed on the paper, so that the two fine steel points may be on the given line (from which the other angular lines are to be drawn), and the centre of the instrument coincide with the given angular point on such line. This done, press the protractor gently down, which will fix it in position by means of very fine points on the under side. It is now ready to lay off the given angle, or any number of angles that may be required, which is done by turning the indices till the forward vernier reads the required

angle. Then press lightly downwards the branches D, D′, which will cause the points to make punctures in the paper at opposite sides of the circle; and the line joining these punctures will pass through the given angular point, if the instrument was first correctly set. In this manner, at one setting of the instrument, a great number of angles, or a complete circular protractor, may be laid off from the same point. The instrument is furnished with a clamp and tangent screw motion, T, by means of which the verniers are set with accuracy; and as there are two of them, the one forms a check upon the other, as the reading of the back-angle vernier should always be exactly 180° more than the reading of the first. In turning the indices to read any desired angle, the clamp must first be loosened, and the indices set to the division on the limb indicating the desired angle; then tighten the clamp, and perfect the reading by the tangent screw, T.

THE T-SQUARE AND SEMICIRCULAR PROTRACTOR.

A very valuable method, by which a traverse* can be



most expeditiously as well as accurately plotted with the T-

* The term "traverse" is applied to a survey made with a chain and theodolite.

square and semicircular protractor, is thus described by Mr. Howlett, late chief draughtsman, Royal Ordnance Office, in vol. i. of "Papers on Subjects connected with the Duties of the Royal Engineers:"—

"As, when away from home, it seldom happens that the surveyor can obtain a good drawing board, or even a table with a good straight edge, I fix a flat ruler, A, to the table B B B, by means of a pair of clamps, C, D, and against this ruler I work the pattern square, E, one side of which has the stock flush with the blade; or, if a strait-edged board be at hand, then the square may be turned over, and used against that edge instead of the ruler A. Here, then, is the most perfect kind of parallel ruler that art can produce, capable of carrying the protractor over the whole of a sheet of blotting paper of any size, and which may be used upon a table of any form. It is convenient to suppose the north on the left hand, and the upper edge of the blade to represent the meridian of the station.

"The protractor is held in the hand while the vernier is set, which is an immense comfort to the sight; and it will be seen that, as both sides of the arm are parallel with the zero and centre, the angle may be drawn on the paper against either side, as the light or other circumstances may render desirable.

"From this description and a mere glance at the engraving, it is clear that angles taken with the theodolite can be transferred to the plot as accurately as the protractor can be set, namely, to a single minute, and that, too, in a rapid and pleasant manner.

"By means of the notch at the end of the arm, this instrument may be used in the manner of a circular protractor, should a square not be at hand."

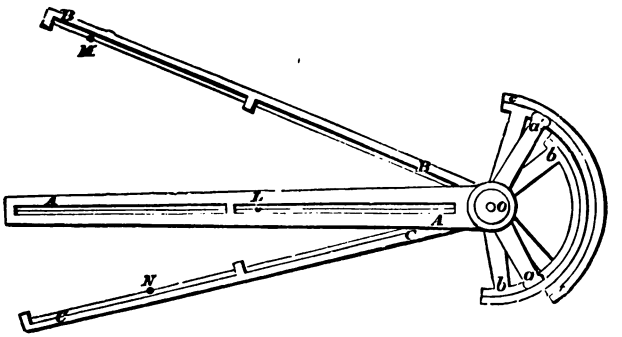
Metcalf's protractor is another semicircular protractor, a modification of Howlett's in which the radial arm is turned into a scale, so that distances may be set off at the same time that an angle is protracted. There is a scale on each edge of the radius, and the vernier is double, so as to apply to either. Diagonal scales corresponding to those on the arm of the instrument are engraved upon it. With either of these semicircular protractors there is no check as to the exact setting of the instrument over the centre of the station, such as is afforded by the circular protractor when both arms are used. It must also be borne in mind that, in plotting an extensive plan, the errors arising from the expansion and contraction of the paper can only be avoided by laying down in the first place a protractor and scales upon the paper itself, from which the angles and distances are afterwards to be measured.

THE STATION POINTER.

When the pri[illegible]s of a country have been laid down by the m[illegible]inted out, the details may be

put in with great rapidity by means of the instrument which we are now about to describe.

A A, B B, C C, are three arms movable about a common centre, O, and carrying three fine wires stretched quite tight, the prolongation of which would pass exactly through the centre, O. The arms B B and C C carry each a graduated arc, *b b* and *c c*; and the arm A A carries two verniers, *a a'*, adapted to the graduated arcs *b b* and *c c* respectively.



The angles L O M and L O N, subtended, at one of the points which we wish to put in, by L, M, and N, three of the principal points of the survey already laid down, having been observed by means of the prismatic compass, or pocket sextant, the arms of the station pointer are opened out till the verniers point out these angles upon the graduated limbs, *b b* and *c c*, respectively. The station pointer being then placed upon the paper, and moved about till the fine wires pass exactly over the stations L, M, N, as marked already upon the plot, the centre will be exactly over the point to be filled in, and its place is to be marked by passing a pricking point through a small opening which is made at the centre to serve this purpose.

The station pointer is peculiarly adapted for laying down the positions of the soundings in a marine survey. If the boat, when a sounding is taken, be in a line with two objects on shore, previously laid down on the chart, an angle is taken with the sextant between this line and a third object also previously laid down on the chart; either of the arms B B or C C is then set at this angle with the centre arm A A, and the latter being laid on the above line, and the former made to pass through the third object on the chart, the centre

of the instrument will be over the required point to be pricked off. If the boat be not in a line with two objects previously laid down, the two angles between three objects previously laid down must be taken with the sextant, and the station point be set and used to fill in the required point in the manner already described.

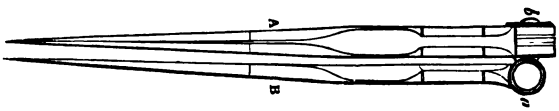
CHAPTER V.

COPYING INSTRUMENTS.

TRIANGULAR COMPASSES.

Copies of drawings are very frequently required either of the same dimensions as the original or upon some other scale. To assist in the production of copies of the same dimensions as the original, a convenient instrument is found in the triangular compass.

The most usual form of triangular compasses is constructed by jointing a third leg to the centre pin of the head-joint of



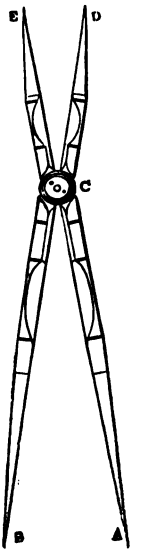
the ordinary dividers, so that this leg, turning both with the centre pin and upon its own joint, has a universal motion.

The mode of using this instrument is to set its three points to coincide, in the first instance, with any three points on the original, and then transfer them to the copy. After this first step the two points of the legs A must be set upon two points of the drawing already copied, and the point of the third leg B made to coincide with a new point of the drawing, that is, one not yet copied; then, by placing the two first points on the corresponding points in the copy, the third point of the compasses will transfer the new point to the copy.

WHOLES AND HALVES.

Drawings may be copied so that all lines and distances in them may be reduced to one-half, or enlarged to double their length, by means of the compasses called wholes and halves,

because the longer legs being twice the length of the shorter, when the former are opened to any given length, the shorter ones will be opened to half that length. These compasses are also adapted for dividing lines by continual bisections—for which purpose, in fact, they are chiefly used. To effect this the compasses must first be opened until the distance between the points A, B, is equal to the entire length of the line to be divided, and the distance between the points D, E, set off from either end of the line, will then bisect it. The compasses being now closed until the distance between A and B is equal to one of the divisions just laid down, the distance between D and E will divide the line into four equal parts, and by repeating the operation, it will be divided into eight equal parts, then into sixteen, and so on.



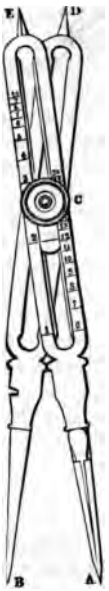
For purposes of copying, they are superseded by the proportional compasses.

PROPORTIONAL COMPASSES.

By mean of this ingenious instrument drawings may be reduced or enlarged, so that all the lines of the copy, or the area or solids represented by its several parts, shall bear certain proportions to the lines, areas, or solids of the original drawing. They will also serve to inscribe regular polygons in circles, and to take the square roots and cube roots of numbers. In the annexed figure the scale of lines is placed on the leg A E, on the left-hand side of the groove, and the scale of circles, on the same leg, on the right-hand side of the groove. The scale of plans and solids are on the other face of the instrument. To set the instrument, it must first be accurately closed, so that the two legs appear but as one; the nut C being then unscrewed, the slider may be moved until the line across it coinsides with any required division upon any one of the scales. Now tighten the screw, and the compasses are set.

To reduce or enlarge the Lines of a Drawing.—The line across the slider being set to one of the divisions, 2, 3, 4, &c., on the scale of lines, the points A, B, will open to double, triple, four times, &c., the distances of the points D,

E (Euc. vi. prop. 4). If, then, the points A and B be opened to the lengths of the lines upon a drawing, the points D and E will prick off a copy with the lines reduced in the proportion of $\frac{1}{2}$ to 1, $\frac{1}{3}$ to 1, $\frac{1}{4}$ to 1, &c.; but if the points D and E be opened to the lengths of the lines upon a drawing, the points A and B will prick off a copy with the lines enlarged in the proportions of 2 to 1, 3 to 1, 4 to 1, &c.



To inscribe in a Circle a regular Polygon of any number of Sides from 6 *to* 20.—The line across the slider being set to any number on the scale of circles, and the points A and B being opened to the length of any radius, the points D and E will prick off a polygon of that number of sides in the circle described with this radius: thus, if the line across the slider be set to the division marked 12 on the scale of circles, and a circle be described with the radius A B, D E will be the chord of a $\frac{1}{12}$th part of the circumference, and will prick off a regular polygon of 12 sides in it.

To reduce or enlarge the Area of a Drawing.—The numbers of the scale of plans are the squares of the ratios of the lengths of the opposite ends of the compasses, when the line across the slider is set to those numbers; and the distances between the points being in the same ratio as the lengths of the corresponding ends (Euc. vi. prop. 4), the areas of the drawings, and of the several parts of the drawings, pricked off by these points, will have to one another the ratio of 1 to the number upon the scale of plans to which the instrument is set (Euc. vi. props. 19, 20; and xii. prop. 2). Thus, if the line across the slider be set to 4 on the scale of plans, the distance between the points A and B will be twice as great as the distance between D and E; and if A and B be opened out to the lengths of the several lines of a drawing, D and E will prick off a copy occupying $\frac{1}{4}$th the area; if the line across the slides be set to 5 on the same scale, the distances between the points will be in the ratio of 1 to $\sqrt{5}$, and the area of the copy pricked off by the points D and E will be $\frac{1}{5}$th of the area of the drawing, of which the lines are taken off by A and B: conversely, if the lines of the drawing be taken off by the points D and E, the points A and B will prick off a copy, of which the area will be 4 times or 5 times as great, according

as the line across the slider is set to the division marked 4 or 5 on the scale.

To take the Square Root of a Number.—The line across the slider being set to the number upon the scale of plans, open the points A and B to take the number from any scale of equal parts (p. 22), then the points D and E applied to the same scale of equal parts will take the square root of the number. Thus, to take the square root of 3, set the line across the slider to 3, open out the compasses till A and B take off 3 from any scale of equal parts, and the points D and E will take off 1·73, which is the square root of 3, from the same scale of equal parts. A mean proportional between two numbers, being the square root of their product, may be found by multiplying the numbers together, and then taking the square root of the product in the manner explained above.

The numbers of the scale of solids are the cubes of the ratios of the lengths of the opposite ends of the compasses, when the line across the slider is set to those numbers; so that, when this line is set to the division marked 2 upon the scale of solids, the distance between the points A and B will give the side of a solid of double the content of that of which a like side is given by the distance of the points D and E; when the line is set to 3, the respective distances of the points will give the like sides of solids, the contents of which will be in the proportion of 3 to 1; and so on.

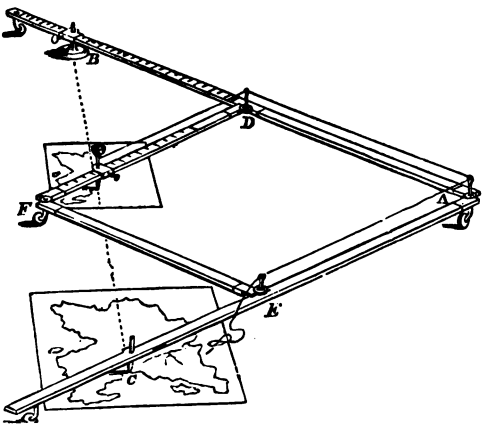
The Cube Root of a given number may be found by setting the line across the slider to the number upon the scale of solids, and, opening the points A, B to take off the square of number upon any scale of equal parts, the points D, E will then take off the required cube root from the same scale.

THE PANTAGRAPH.

The pantagraph consists of four rulers, A B, A C, D F, and E F, made of stout brass. The two longer rulers, A B and A C, are connected together by, and have a motion round, a centre at A. The two shorter rulers are connected in like manner with each other at F, and with the longer rulers at D and E; and, being equal in length to the portions A D and A E of the longer rulers, form with them an accurate parallelogram, A D F E, in every position of the instrument. Several ivory castors support the machine parallel to the paper, and allow it to move freely over it in all directions. The arms, A B and

D F, are graduated and marked $\frac{1}{2}$, $\frac{1}{3}$, &c., and have each a sliding index, which can be fixed at any of the divisions by a milled-headed clamping screw, seen in the engraving. The sliding indices have each of them a tube, adapted either to slide on a pin rising from a heavy circular weight called the fulcrum, or to receive a sliding holder with a pencil or pen, or a blunt tracing-point, as may be required.

When the instrument is correctly set, the tracing-point, pencil, and fulcrum will be in one straight line, as shown by the dotted line in the figure, and which may be proved by stretching a fine string over them. The motions of the tracing-point and pencil are then each compounded of two circular motions, one about the fulcrum, and the other about the joints at the ends of the rulers upon which they are respectively placed. The radii of these motions form sides about equal angles of two similar triangles, of which the straight line B C, passing through the tracing-point, pencil, and fulcrum, forms



the third side. The distances passed over by the tracing-point and pencil, in consequence of either of these motions, have then the same ratio, and, therefore, the distances passed over in consequence of the combination of the two motions have also the same ratio, which is that indicated by the setting of the instrument.

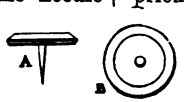
Our engraving represents the pantagraph in the act of

reducing a plan to a scale of half the original. For this purpose the sliding indices are first clamped at the divisions upon the arms marked ½; the tracing-point is then fixed in a socket at C, over the original drawing; the pencil is next placed in the tube of the sliding index upon the ruler D F, over the paper to receive the copy; and the fulcrum is fixed to that at B, upon the ruler A B. The machine being now ready for use, if the tracing-point at C be passed delicately and steadily over every line of the plan, a true copy, but of one-half the scale of the original, will be marked by the pencil on the paper beneath it. The fine thread represented as passing from the pencil quite round the instrument to the tracing-point at C, enables the draughtsman at the tracing-point to raise the pencil from the paper, whilst he passes the tracer from one part of the original to another, and thus to prevent false lines from being made on the copy. The pencil-holder is surmounted by a cup, into which sand or shot may be put, to press the pencil more heavily on the paper, when found necessary.

If the object were to enlarge the drawing to double its scale, then the tracer must be placed upon the arm D F, and the pencil at C; and if a copy were required of the same scale as the original, then, the sliding indices still remaining at the same divisions upon D F and A B, the fulcrum must take the middle station, and the pencil and tracing-point those on the exterior arms, A B and A C, of the instrument.

The successful use of the pantagraph in copying very minute and complicated drawings can only be attained by perseverance and experience, and we therefore proceed to mention some of the other means employed for the attainment of the same object. In fact, while the pantagraph affords the most rapid means of reducing a drawing, we cannot recommend its use for enlarging a copy, or even for copying upon the same scale.

To produce a Copy of the same Size as the Original. First Method.—Lay the original drawing upon the sheet of paper intended for the copy, and fix them together by means of weights or drawing-pins.* 2. With a fine needle† prick



* The drawing-pin consists of a brass head, with a steel point at right angles to its plane. A represents it as seen edgewise, and B as seen from above.

† See pricking point, page 4.

through all the angles and principal points, making corresponding punctures in the paper beneath. 3. Draw upon the copy such of the lines on the original as are straight, or nearly so, by joining the points thus marked upon the paper. 4. Set off such other points upon the copy, by means of the compasses, as may be desirable, and draw the curved lines upon tracing-paper placed over the drawing. 5. Fill in the lines indicated by the points set off by the compasses, and transfer the curved lines from the tracing-paper to the copy, by rubbing the back of the tracing-paper with powdered black-lead, placing it in its correct situation upon the copy, and passing a blunt tracing-point* over the lines drawn upon it.

Second Method.—A sheet of tracing-paper having the under side rubbed over with powdered black-lead may be placed upon the paper intended for the copy. The original being then placed over this, the tracing-point may be carefully and steadily passed over all the lines of the drawing with a pressure proportioned to the thickness of the paper; and the paper beneath will receive corresponding marks, forming an exact copy, which is afterwards to be inked in.

Third Method.—The drawing is placed upon a large sheet of plate glass called a copying-glass, and the paper to receive the copy placed over the drawing. The glass is then fixed in such a position as to have a strong light fall upon it from behind, and shine through it. By this means the original drawing becomes visible through the paper placed over it, and a copy can be made with precision and ease, without any risk of soiling or injuring the original.

To copy with nicety upon a Reduced or Enlarged Scale.—For this purpose we may have recourse to the method of squares, by which, with the aid of the proportional compasses, the most minute detail may be copied with great accuracy. This may, perhaps, be best shown by an example.

Let Fig. 1 in the following engraving represent a plan of an estate, which it is required to copy upon a reduced scale of one-half. The copy will therefore be half the length and half the breadth, and, consequently, will occupy but one-fourth of the space of the original. Our subject is a map of an estate, but the process would be precisely the same if it were an architectural, mechanical, or any other drawing.

* The eye end of the pricking needle, or the fine point of a porcupine's quill, may be used for this purpose.

1. Draw the lines F I and F G at right angles to each other. 2. From the point F, towards I and G, set off any number of equal parts, as F *a*, *a b*, *b c*, &c., on the line F I, and F *i*, *i k*, *k l*, &c., on the line F G. 3. From the points on the line F I

Fig. 1.

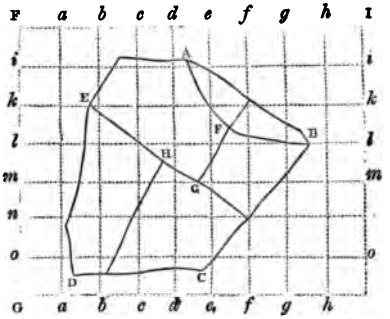
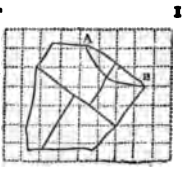


Fig. 2.



draw lines parallel to the other line F G, as *a a*, *b b*, *c c*, &c., and from the points on F G draw lines parallel to F I, as *i i*, *k k*, *l l*, &c., which being sufficiently extended towards G and I, the whole of the original drawing will be covered with a reticule of small but equally sized squares.

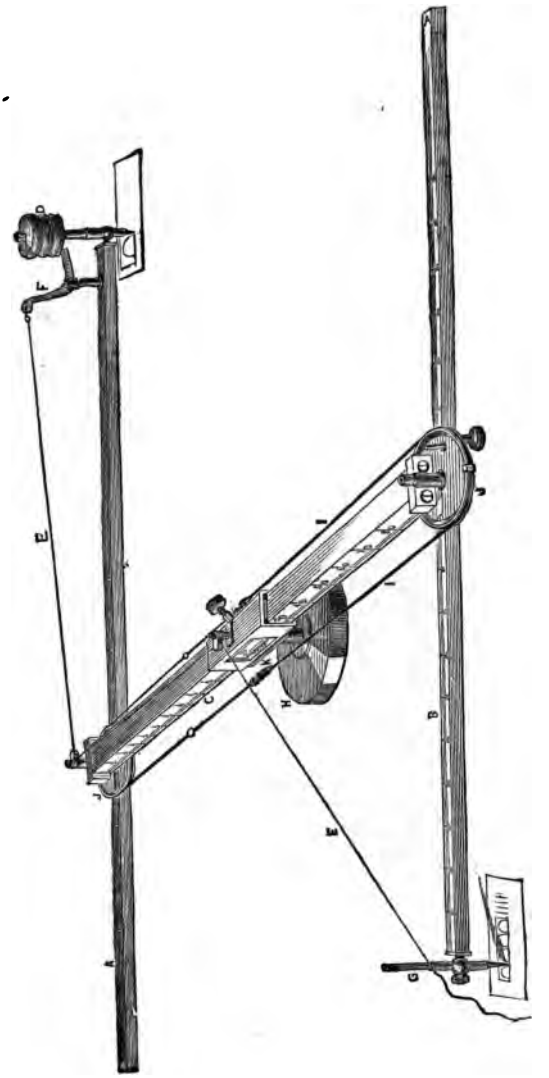
This done, draw upon the paper intended for the copy a similar set of squares, but having each side only one-half the length of the former, as is represented in Fig. 2. It will now be evident that, if the lines of the plan A B, B C, C D, &c., Fig. 1, be drawn in the corresponding squares of Fig. 2, a correct copy of the original will be produced, and of half the original scale. Commencing then at A, observe where, in the original, the angle A falls, which is towards the bottom of the square marked on the top *d e*. In the corresponding square, therefore, of the copy, and in the same proportion towards the left-hand side of it, which should be determined by the use of the proportional compasses described at p. 63, place the same point in the copy. From thence finding, by the proportional compasses, the point on the bottom line of that square where the curved line A F crosses, which is about two-fifths from the left-hand corner towards the right, cross it similarly in the copy. Again, as it crosses the right-hand bottom corner of the second square below *d e*, describe it so

in the copy; and by means of the proportional compasses find the points where it crosses the lines *f f* and *g g*, above the line *l l*, by taking the distances of such crossings from the nearest corner of a square in the original, between the large points of the proportional compasses, and with the small points at their opposite end setting off the required crossing on the corresponding lines on the copy. Lastly, determine the place of the point B in the third square below *g h* on the top line; and a line drawn from A in the copy, through these several points to B, will be a correct reduced copy of the original line. Proceed in like manner with every other line on the plan, and its various details, and you will have the plot or drawing laid down to a small scale, yet bearing all the proportions in itself exactly as in the original.

It may appear almost superflous to remark, that the process of enlarging drawings by means of squares is a similar operation to the above, except that the points are to be determined in the smaller squares of the original, and transferred to the larger squares of the copy. The process of enlarging, under any circumstances, does not, however, admit of the same accuracy as that of reducing; and when an enlarged drawing is required, it is best to construct it anew from the original data.

THE EIDOGRAPH.

The pantagraph just described requires four supports upon the paper, and from this cause, and from its numerous joints, its action is apt to be unsteady. An instrument to avoid these defects was invented by Professor Wallace in 1821. This instrument, called the eidograph, is more regular in its action than the pantagraph, as will readily be understood from the following description of its construction, by which it will be seen that there is only one point of support upon which the entire instrument moves steadily and regularly; and the joints, if we may so term them, consist of fulcrums fitting in accurately ground bearings, the motion round these fulcrums being capable of adjustment for regularity as well as accuracy. It also possesses the further advantage over the pantagraph, that it may be set with equal facility to form a reduced copy bearing any proportion whatever to the original, while the pantagraph can only be set to vary the relations between the original and the copy in the few proportions which are *specifically marked upon* it.


A
B
C
D
E
F
G
H
I
J
K
L

The point of support of the eidograph is a heavy weight, H, formed exteriorly of brass and loaded internally with lead, and having three or four small needle points to keep it steady on the paper. The pin, forming the fulcrum upon which the whole instrument moves, projects from the centre of this weight on its upper side, and fits into a socket attached to a sliding box, K. The fulcrums are ground to fit very accurately. The centre beam, C, of the instrument fits into and slides through, the box K, and may thus be adjusted to any desired position with respect to the fulcrum, and then fixed by a clamping screw attached to the box. Deep sockets are attached to each end of the centre beam, into which are accurately fitted the centre pins of two pulley wheels, J, J. These pulley wheels are made most exactly of the same diameter, and have two steel bands, I I, attached to their circumferences, so that they can move only simultaneously, and to exactly the same amount. By means of screw adjustments these bands can have their lengths regulated so as to bring the arms of the instrument into exact parallelism, and, at the same time, to bring them to such a degree of tension as shall give to the motions of the arms the required steadiness, which forms one of the advantages of the instrument over the pantagraph. The arms, A and B, of the instrument pass through sliding boxes upon the under side of the pulley wheels, these boxes, like that for the centre beam, being fitted with clamping screws, by which the arms can be fixed in any desired position. At the end of one of the arms is fixed a socket with clamping screw, to carry a tracing-point, G, and at the end of the other is a socket for a loaded pencil, D, which may be raised when required by a lever, F F, attached to a cord which passes over the centre of the instrument to the tracing-point. The centre beam C, and the arms A, B, are made of square brass tubes, divided exactly alike into two hundred equal parts, and figured so as to read one hundred each way from their centres, and the boxes through which they slide have verniers, by means of which these divisions may be subdivided into ten, so that with their help the arms and beam may be set to any reading containing not more than three places of figures. A loose leaden weight is supplied with the instrument to fit on any part of the centre beam, and keep it in even balance when set with unequal lengths of the centre beam on each side of the fulcrum.

The pulleys, J J, being of exactly equal size, when the steel

bands I I are adjusted so as to bring the arms of the instrument into exact parallelism, they will remain parallel throughout all the movements of the pulleys in their sockets, and thus will always make equal angles with the centre beam. If, then, the two arms and the centre beam be all set so that the readings of their divisions are the same, a line drawn from the end of one arm across the fulcrum to the end of the other arm will form with the beam and arms two triangles, having their sides about equal angles proportionals, and being, therefore, similar; hence any motion communicated to the end of one arm will produce a similar motion at the end of the other, so that the tracing-point being moved over any figure whatever, an exactly similar figure will be described by the pencil.

To adjust the Eidograph, and examine its accuracy.—Set the indices of all three verniers to coincide with the zero divisions on the centre beam and arms, and make marks at the same time with the tracer and with the pencil; then move the pencil point round until it comes to the mark made by the tracer, and if the tracer at the same moment comes into coincidence with the mark made by the pencil, the arms are already parallel, and the instrument consequently in adjustment; but if not, make a second mark with the tracer in its present position, and bisecting the distance between this mark and the mark made by the pencil, bring the tracer exactly to this bisection by turning the adjusting screws on the bands. The instrument being now in adjustment, if the zero division be correctly placed on the arms and beam, the pencil point, tracer, and fulcrum will be in the same straight line, and they will still remain so when the instrument is set to give the same readings on the three scales, whatever those readings may be, if the dividing of the instrument be perfect.

The instrument being adjusted, we have next to set it so as to make the dimensions of a copy, traced by its means, bear the desired proportion to the original. It must be borne in mind that the divisions on the instrument are numbered each way from the centres of the beam and arms up to 100, and that the verniers enable us to read decimals or tenths of a division; so that if the indices of the verniers were a little beyond any divisions, as 26, and the third stroke of the verniers coincided with the divisions marked 29, the reading would be 26·3. Now suppose it were required to set the instrument so that the proportion of the copy to the original should be that

of one number, a, to another number b. Suppose x to represent the reading to which the instrument should be set, then the centre beam and arms are each divided at their fulcrums into portions whose lengths are $100-x$ and $100+x$ respectively, and consequently $\frac{100-x}{100+x}=\frac{a}{b}$, from which we find that the required reading $x=\frac{100\,(b-a)}{b+a}$; thus, if the proportions are as 1 to 2, we have $x=\frac{100\,(2-1)}{2+1}=\frac{100}{3}=33{\cdot}3$, and the instrument must be set with the third divisions of the verniers beyond the indices on the third divisions of the instrument beyond the 33rd. We have, therefore, the following simple rule: Subtract the lesser term of the proportion from the greater, and multiply it by 100 for a dividend, add together the two terms of the proportion for a divisor, and the quotient will give the reading to which the instrument is to be set. The following readings are thus obtained:—

Proportions.	Readings.	Proportions.	Readings.
1 : 2	33·3	2 : 3	20
1 : 3	50	2 : 5	42·9
1 : 4	60	3 : 4	14·3
1 : 5	66·7	3 : 5	25
1 : 6	71·4	4 : 5	11·1

When the copy is to be reduced, the centre beam is to be set to the reading found, as above, on the side of the zero next to the arm carrying the pencil point, and this arm is

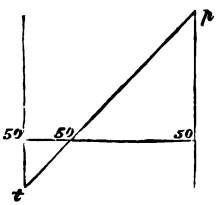


Fig. 1.

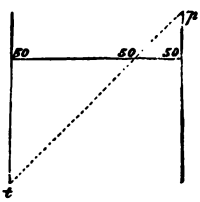


Fig. 2.

also to be set to the same reading on the side of its centre or *zero nearest the* pencil end, while the tracer arm is to be set

with the reading furthest from the tracer. When the copy is to be enlarged, these arrangements must of course be reversed: thus, 50 being the reading for the proportion 1 : 3, Fig. 1 will represent the setting to make a copy having its linear dimensions three times those of the original; where *p* represents the position of the pencil point, *t* that of the tracer, and F the place of the fulcrum. Fig. 2 represents in the same way the setting to make the linear dimensions of the copy one-third of those of the original.

After all, the most perfect copying-machine is the photographic camera. In fact, photography has now fully taken its place as an auxiliary to engineering operations. By its use the mechanical engineer is enabled to send forth *correct* representations of his machinery; and works of civil engineering have their monthly progress recorded, and the results sent home, to give ocular proof of their truth to chiefs and directors. A practical knowledge of photographic processes has hence become almost a necessary, certainly a most desirable portion of every young engineer's education. Several special manuals on the art of photography, in English and French, are to be found. Of the apparatus used for the reduction of maps and plans a full description will be found in Part III. of this volume.

CHAPTER VI.

INSTRUMENTS FOR MEASURING LINES AND AREAS ON PLANS.

THE OPISOMETER.

THIS simple instrument measures the length of roads, rivers, fences, walls, &c., on any map or plan which is drawn to a scale, without requiring any arithmetical calculations.

The principle of the opisometer is that after having been applied to any line it retraces or measures backwards precisely the same length on the scale with which the line is to be compared. It consists of a milled wheel, with a steel screw for its axis, mounted on a convenient handle. To measure the length of a line, as the distance between two towns by

the road traced upon a map, turn the milled wheel up to one end of the screw until it stops, and place the instrument on the map in an upright position, as represented in the draw-

ing, the wheel resting upon one extremity of the line to be measured; then run the wheel along the road, following every bend as closely as possible. Care must be taken to keep the wheel in contact with the paper, but the pressure need not be such as to injure the map. When the wheel has arrived at the other extremity of the line, lift the instrument carefully from the paper, and carrying it to the zero end of the scale, run the wheel backwards along the scale until it stops at the same end of the screw from which the measurement began; the division of the scale at which the wheel stops shows the length of the line measured on the map. Should the scale be shorter than the line measured, when the wheel arrives at the end, carry it to the zero mark again as often as may be necessary, counting the number of repetitions.

The difficulty of measuring lines of double curvature, such as a rhumb line, *i.e.*, the line of a ship's course on a globe, is entirely removed by the use of the opisometer.

The accuracy of the result given by the opisometer is unaffected by the dimensions of the instrument itself, and depends entirely on the care with which it is used. The chief point is to see that the handle of the instrument is perpendicular to the surface at the beginning and end of each step of the measurement.

The computation of the area represented by a plan, especially if the outline be very irregular, is both a tedious task

and liable to many sources of error, which, after all, forbid us from looking at the result as any more than a careful approximation. In the first place, the irregularity of the outline is dealt with by drawing straight lines, which, in the estimation of the computer, shall go as far outside the figure on one part as they fall inside on another, so as to form a rectilinear figure estimated to be equal to the plan. This is called the give-and-take principle, and is, of course, a mere guess, depending for its degree of accuracy upon the skill and practice of the operator. Then the polygon thus formed has either to be divided into triangles, the area of which must be separately computed, or a triangle must be constructed, by the principles of geometry, equal to the whole polygon, and then the area of this triangle will be the estimated area of the surface represented by the plan. Any means of instrumentally getting at the computation with greater expedition, without producing greater inaccuracy than this mode of computation, must be hailed as a boon, and we have a very simple and inexpensive instrument, which is now much used for this purpose, in the

COMPUTING SCALE, OR COMPUTER.

The computer is designed to measure only the areas of figures constructed to one particular scale, and as many com-

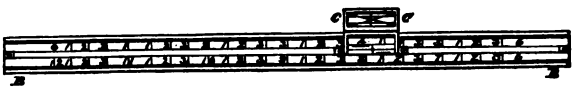


Fig. 1.

puters, therefore, would be required by the surveyor as he adopted scales for his plans. The simplicity, and consequently inexpensive nature, of the instrument prevent this from being felt as a serious disadvantage.

The computer (Fig. 1) consists of a rule, B B, of box-wood, graduated and figured to show the number of acres and roods in a slip of land of a given width. In that from which the annexed figure is drawn, the graduations on the rule itself show the number of acres and roods in a slip of land one chain wide, and it is adapted to a plan of 3 chains to an inch. The scale occupies 20 inches of the length of the rule, and therefore represents 60 chains in length, and an area of 60

square chains, or 6 acres, in a slip of 1 chain wide. These 20 inches are therefore divided into 6 equal parts for single acres, and each of these parts is divided into four equal subdivisions to represent roods. Along the centre of the rule is an undercut groove, and the rule is graduated on each side of this groove, so that it reads forward from left to right on the upper side of the groove, commencing at 0 and terminating at 6 acres, and then reads back again from right to left on the under side of the groove, commencing at 6 acres and terminating at 12 acres. Into the groove is fitted, so as to slide freely along it, a tongue or slip of brass, A A, represented in

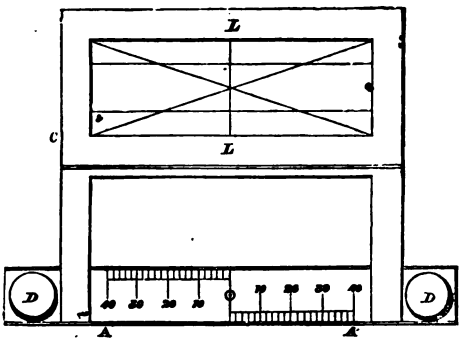


Fig. 2.

Fig. 2 on an enlarged scale, which has an index drawn across its centre, and on each side of this index a distance equal to one of the subdivisions on the rule is divided into 40 equal parts to represent perches. These divisions are placed, those on the left of the index to read with the divisions of the scale on the upper side of the groove, and those on the right of the index to read with divisions on the under side of the groove. To the tongue A A is attached a frame, C C, which passes over the side of the rule, and lies flat upon the paper on which the rule is placed when in use. The handles D, D, enable the tongue and attached frame to be moved with facility along the divided scale. The frame encloses a piece of thin horn, on which are ruled two lines parallel to the rule, at the distance apart which represents a chain, in the present instance $\frac{1}{8}$ of an inch, and the centre of this enclosure being determined by

the intersection of its diagonals, a line L L, called the index line, is drawn through this centre at right angles to the parallel lines, and in the same straight line with the index on the brass tongue.

The following is the mode of using the computer:—The plan, which, as has been already stated, has been constructed on the same scale as the computer to be applied to it, is ruled over with parallel lines at distances apart representing one chain, in this case $\frac{1}{8}$ of an inch, and so dividing the whole plan into slips of one chain in width. The computer, having its index set to zero on the scale, is now placed on the paper parallel with these lines, in such a position that the parallel lines on the horn move along in coincidence with the first two lines, enclosing the first slip of land into which the plan has been divided, and that the index line, L L, lies across the boundary of one end of this slip; and the tongue being then moved along the scale until the index line crosses the boundary at the other end of the slip, the position of the index will indicate on the scale the content of the first slip of land. The instrument must now be moved without shifting the index, and placed with the index line across the boundary at the beginning of the next slip, and the tongue is again to be slid along until the index line crosses the boundary at the other end, when the position of the index will indicate the content of the two slips; and proceeding in this way from slip to slip until the whole have been passed over, the index will finally show the content of the entire surface represented by the plan. When this content is more than that represented by the entire length of the scale (which in the present case is 6 acres), as soon as the index reaches the 6 at the end of the scale the instrument should be turned round, care being taken to place the index line again in exactly the same position; and the operation can then be continued until the index comes back to its original position, and indicates 12 acres, when it must again be turned, and a note made that 12 acres have been computed. Proceeding in this way, the ultimate reading of the index, added to the number of 12 acre pieces already noted, will give the entire content in acres, roods, and perches.

At the beginning and end of each slip the operator must exercise his judgment as to the proper position of the index line, so that in crossing the boundary he shall add as much on the one side of the line as he cuts off on the other. Practice will

also enable him to judge of the best direction for his parallel lines, so that the contents of the extreme slips may be best estimated.

Instead of ruling lines over the plan itself, if these be ruled on a transparent paper, such as is used for tracing, they can be shifted round upon the plan until they come into a position which will best suit the operator's purpose. This method has the additional advantage of avoiding any injury to the plan itself, either by ruling it over, or by making marks to assist in resetting the instrument each time the index arrives at one end of the scale.

THE POLAR PLANIMETER.

The method of taking the areas of figures by the computer just described, though more expeditious than that of dividing the figure into triangles, and computing their contents by geometrical rules, is still a troublesome operation, and the correction for the irregularity of outline upon the give-and-take principle is still but guesswork; consequently an instrument which will give the results with greater facility and accuracy has been a great desideratum.

There is a very elegant instrument, of French origin, called the totalisateur, which accomplishes this object; but its expense alone would prevent it from coming into common use. The instrument, however, which we proceed to describe leaves nothing to be desired either in point of simplicity of construction, and consequently moderate price, facility of use, or accuracy of the results obtained. The whole operation of taking an area with this instrument consists in passing a point round the outline of the figure, and the operator is astonished by the marvellous accuracy of the results obtained, no less than by the extreme simplicity of the instrument with which it is accomplished.

This instrument, called the polar planimeter, is the invention of Mr. J. Amsler, professor of mathematics at Schaffhausen, and is sold in England by Messrs. Elliot Brothers, of Charing Cross. It consists essentially of two arms jointed together, so as to move with perfect freedom in one plane, and a wheel which is attached to one of the arms, and turning on this arm as an axis, records by its revolutions the area of a figure traced out by a point on the arm to which it is attached, while a point on the other arm is made a fixed centre, about which the instrument revolves.

Thus, let A B, B C represent the two arms, of which B C carries a wheel at D, revolving freely in a plane at right angles to B C, and let the arms be opened until the line A D drawn from a point A on the arm A B to the wheel is at right angles to B C; then if, without varying the angle between the arms, the instrument be moved round A as a centre, any point C on B C will describe a circle which will constitute a zero or datum line, the wheel at D then moving entirely perpendicular to its own plain, and consequently without turning upon its axis; again, let the arms be opened until B D C comes into the position B D′ C′, and from A draw A E perpendicular to C′ B, produced if necessary, and A F at right angles to A D′; then if, with this new position of the arms, the instrument is again moved round A as a centre, the point C′ will describe another circle, and while the point D′ moves through a distance represented by A F perpendicular to A D′, the wheel will slip through the distance F E at right angles to its own plane, and will run through the distance E A parallel to it, which latter distance alone it will therefore record. Now the triangles F E A and A E D′ being similar, E D′ has the same ratio to A D′ that A E has to A F, and, therefore, while the point D′ actually describes an arc of the circle whose radius is A D′, the circumference of the wheel rolls through a distance equal to the corresponding arc of a circle whose radius is D′ E. Now, from Euc. Bk. ii. props. 12 and 13, we have $AC^2 = AB^2 + BC^2 - 2BC, BD$, and $AC'^2 = AB^2 + BC'^2 + 2BC,$ BE, and therefore $AC'^2 - AC^2 = 2BC(BE + BD') = 2BC \times D'E$: but the area of the ring contained between the circles described by the points C and C′ is equal to $\pi(AC'^2 - AC^2)$, and therefore to $2\pi D'E \times BC$, *i.e.*, to the *circumference* of the circle whose radius is D′ E, which is the distance rolled through by the circumference of the wheel, multiplied into the distance B C from the joint B to the tracing-point C. If the arms, instead of being opened further apart, had been brought closer together, so that C′ in its second position had described a circle within the datum or zero circle, the area of the ring between the two circles would still have been

measured by the product of B C into the distance described by the circumference of the wheel. Now, when the point C is moved over any outline while the centre A remains fixed, we have two motions, one of the whole instrument round A, and the other of the arm B C round the joint B; but in going completely round any figure to the point of starting, the arms must at last come back into the same position as they held at first; and, hence, whatever amount the wheel may have turned one way in consequence of a movement about the joint B in one direction, it must have turned back an equal quantity the other way in consequence of a movement about the joint in the opposite direction, and hence the whole of the recorded motion is that due to the rotation of the instrument about the centre A, and measures the areas included between the outline and the datum circle; and since those areas are equal to the distance run by the circumference of the wheel multiplied by B C, the graduations on the wheel, whatever be their lengths, may be made to record the areas in any desired unit of measurement by making the length of B C contain as many of these units as the unit contains of the graduated lengths. The length of the arm A B, and the part of the arm B C upon which the wheel is placed, do not affect the scale of measurement, and the instrument may therefore be constructed without regard to these points, or to the size of the wheel, and regulated solely by the distance B C of the tracing-point C from the joint B. The forms given to the instrument of which the principle has been fully explained above are represented in Figs. 1 and 2. In Fig. 1 the arm A carrying the tracing-point passes through a slide-box J, so that the tracing-point may be set at different distances from the joint, and thus give the areas in different units of measure. In Fig. 2 the arm A is of invariable length, and consequently the areas to be measured can be read off from the instrument only in one kind of standard measure. Those manufactured of this pattern for this country are regulated to record the areas in square inches.

The essential points in the construction of the instrument are as follows:—1. The centre pin C C, the axis I, and the extremity of the tracing-point E must lie all in one plain; and hence great care must be taken not to bend the arm A or the tracer. 2. The roller D must play easily without coming into contact with the vernier. 3. The screw centres on which its axis, I, revolves must be adjusted so as to allow of perfect *freedom* of rotation, and so also must those on which the

centre pin, c c, revolves; these centres have to be greased sometimes with a little sweet oil. 4. The roller D, which moves on the paper, will not bear the least spot of rust or slightest injury without impairing the accuracy of the instrument. 5. The needle point ought to project but very little from its socket. In the instrument represented in Fig. 2, the circumference of the roller measures nearly 2½ inches, and

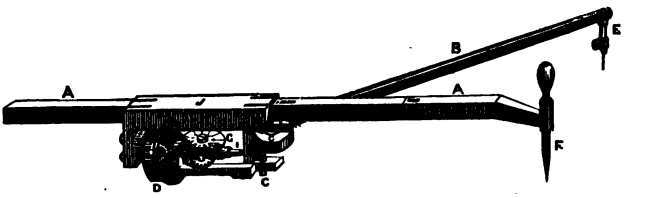


Fig. 1.

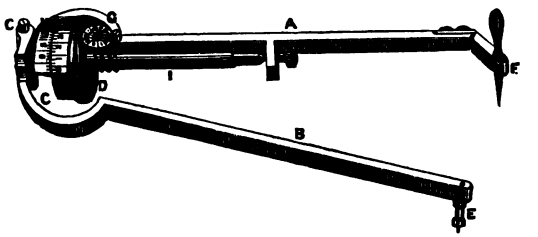


Fig. 2.

the tracing-point being set at such a distance (viz., differing a little from 4 inches) as will make the product of this distance into the circumference of the roller = 10 square inches, every complete revolution of the roller records an area of 10 square inches. The correct setting of the tracing-point is, of course, to be obtained by passing it over a test outline of a surface whose area is accurately known. The roller D, by means of an endless screw on its axis I, acting upon a rack, gives one revolution to the counting wheel, G, for every ten revolutions of its own, and this counting wheel being graduated into ten equal divisions, every one of these records an area of 10 square inches. The primary divisions on the roller D itself being ten in number, each of these records an area of 1 square inch; and, each of these being subdivided into ten

equal parts, and these subdivisions again divided into ten by means of the vernier, the areas are read off to the 100th of a square inch.

In using the instrument, (1) place it upon the paper in such a manner that it rests upon a point of the circumference of the roller D, the tracing-point F, and the needle point E: press the latter point gently on the paper, but not enough to pierce it through, and place above the point E the small weight supplied with the instrument, to keep this point stationary during the operation; or the same result may be obtained by a light pressure of the thumb or finger. (2) Mark any point P (Figs. 3 and 4) on the outline of the figure; and, after setting the tracing-point F on this point, read off the counting wheel G, the roller D, and the vernier H: suppose, for instance, the readings indicated are 2 for the counting wheel, 91 for the roller, and 5 for the vernier; then the number 29·15 must be written down. (3) Carry the tracing-point F round, in the direction of the hands of a watch, with great exactness over the outline of the figure to be measured, until the starting-point is again reached: along straight lines the tracing-point may be guided by a rule: observe the readings again: suppose them to be 4 for the counting wheel, 76 for the roller, and 7 for the vernier; then the number 47·67 must be written down for the second reading. (4) The difference of the two readings gives the areas between the outline and the datum circle P R, and consequently we have two cases to consider: in Fig. 3, where the needle point, E, is outside the figure to

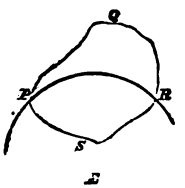


Fig. 3.

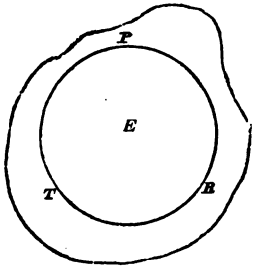


Fig. 4.

be measured, the difference of the two readings gives 18·52 square inches for the areas of the two portions, P Q R and P R S, and consequently of the whole figure P Q R S; in Fig. 4,

where the needle point E is within the figure to be measured, the excess of the second reading over the first gives only the area beyond the datum circle P R T, the result being negative if the figure be less than the datum circle: consequently, the area of the datum circle must be added to the second reading before the first is subtracted from it, and the remainder will give the area of the figure required. The area of the datum circle may be found by first placing the needle point E outside a convenient figure, and taking the difference of the two readings: suppose it to be 171·05, this represents the area of the figure; again placing the needle point within the figure, let the excess of the second reading above the first be 10·64; this represents the excess of the area of the figure above that of the datum circle; consequently the area of this circle is 171·05 — 10·64 = 160·41; this quantity 160·41 is engraved either on the bar A, or upon the small weight supplied with the instrument. Suppose now, in going over a figure with the needle point E within it, the first reading to be 20·95, and the second to be 17·34, then the area would be found as follows:—

Second reading	17·34
Add datum circle	160·41
	177·75
Deduct first reading . . .	20·95
Remainder . . .	156·80

The measured area of the figure on the paper is, therefore, 156·8 square inches.

If, in measuring an area, the 0 or zero on the counting wheel passes the index point while moving forwards, 100·00 must be added to the second reading, and if it passes while moving backwards, 100·00 must be added to the first reading.

If the figure is so large that the tracing-point cannot conveniently be passed round it at one operation, it can be subdivided by drawing straight lines through it, and the contents of the several parts measured separately can be added together to give the total area.

If a large amount of work had to be done in measuring a series of maps or plans, all constructed to one scale, the instrument represented in Fig. 1 could be adapted to measure

the areas to this scale by constructing on the same scale rectangular figure of a given area, and sliding the arm A t such a part of the tube as to give the known area correctly

Roods ...	0	1	2	3
Perches.	..	·250	·500	·750
1	·006	·256	·506	·756
2	·012	·262	·512	·762
3	·019	·269	·519	·769
4	·025	·275	·525	·775
5	·031	·281	·531	·781
6	·037	·287	·537	·787
7	·044	·294	·544	·794
8	·050	·300	·550	·800
9	·056	·306	·556	·806
10	·062	·312	·562	·812
11	·069	·319	·569	·819
12	·075	·325	·575	·825
13	·081	·331	·581	·831
14	·087	·337	·587	·837
15	·094	·344	·594	·844
16	·100	·350	·600	·850
17	·106	·356	·606	·856
18	·112	·362	·612	·862
19	·119	·369	·619	·869
20	·125	·375	·625	·875
21	·131	·381	·631	·881
22	·137	·387	·637	·887
23	·144	·394	·644	·894
24	·150	·400	·650	·900
25	·156	·406	·656	·906
26	·162	·412	·662	·912
27	·169	·419	·669	·919
28	·175	·425	·675	·925
29	·181	·431	·681	·931
30	·187	·437	·687	·937
31	·194	·444	·694	·944
32	·200	·450	·700	·950
33	·206	·456	·706	·956
34	·212	·462	·712	·962
35	·219	·469	·719	·969
36	·225	·475	·725	·975
37	·231	·481	·731	981
38	·237	·487	·737	·987
39	·244	·494	·744	·994

From the areas, however, of the figures on the paper, as giv in square inches by the instrument in Fig. 2, the areas the figures represented according to the scales of so ma

chains to an inch ordinarily made use of, can readily be obtained by removing the decimal point one place to the left, and multiplying the result by the square of the number of chains to the inch, since one square chain is a tenth of an acre; thus, if the measured area be 51·65, and the scale be one chain to an inch, the area represented will be 5·165 acres; if the scale were three chains to an inch, the area represented would be $9 \times 5{\cdot}165 = 46{\cdot}485$ acres. The decimal of an acre contained in the area may be readily converted into roods and perches by multiplication, or these may be taken from the foregoing table, where the roods corresponding to any decimal will be found at the top of the column in which it stands, and the perches will be found on the same horizontal line with the decimal in the column on the extreme left: thus, if the decimal be ·587, at the top of the column in which ·587 is found stands the number 2, and opposite ·587 in the left-hand column is 14; and 2 roods 14 perches is the value of ·587 of an acre.

PART II.

ON RULES AND GAUGES.

The instruments described in this part are of two classes: viz., (1) instruments for the performance of arithmetical computation; and (2) instruments designed for accuracy of measurement.

Under the first head will be included descriptions of

Gunter's Lines,
Gunter's Scale,
Slide-rules.

Under the second,

Callipers and Gauges for the measurement of timber,
Spherometer,
Extensometer,
German-silver Wire-gauge.

SECTION I.

INSTRUMENTS FOR ARITHMETICAL COMPUTATION.

GUNTER'S LINES.

A series of numbers increasing by equal differences is said to be in arithmetical progression; thus, each of the series

0	1	2	3	4	5, &c.,
	1	3	5	7	9, &c.,

is in arithmetical progression, the common difference being 1 *in the first* series and 2 in the second.

A series of numbers increasing by equal ratios is said to be in geometrical progression; thus, each of the series

1	2	4	8	16	32, &c.,
2	8	32	128	512, &c.,	

is in geometrical progression, the common ratio being 2 in the first series and 4 in the second.

In the two examples of arithmetical series given above, it is to be noted that 0 forms a term of the first, but not of the second; and in the two examples of geometrical series 1 forms a term of the first, but not of the second.

Now if the terms of a series of numbers in arithmetical progression, of which 0 forms a term, be written in order over the terms of a series of numbers in geometrical progression, of which 1 forms a term, taking care to place the 0 of the arithmetical series over the 1 of the geometrical series, the terms of the arithmetical series are called logarithms of the corresponding terms of the geometrical series: thus, if we select the first of the series of each class given above,

0	1	2	3	4	5, &c.,
1	2	4	8	16	32, &c.,

the numbers 0, 1, 2, 3, 4, 5, &c., are respectively logarithms of the numbers 1, 2, 4, 8, 16, 32, &c., over which they stand: so also of the series

0	3	6	9	12	15, &c.,
1	5	25	125	625	3125,

the terms of the first are logarithms of the terms, over which they stand, of the second.

Hence it appears that the variety of systems of logarithms is infinite. Only one, however, is made use of for the purposes of arithmetical computation, viz., that in which the arithmetical series whose common difference is 1 is made to correspond with the geometrical series whose common ratio is 10: thus,

Logarithms	0	1	2	3	4	5, &c.,
Numbers	1	10	100	1000	10000	100000, &c.

The logarithms of the numbers between 1 and 10, 10 and 100, &c., are computed by methods which it is not our present business to investigate, and, being registered in due order, form what is termed a table of logarithms.

On examining any system of logarithms, the following remarkable properties will be observed:—

If any two of the logarithms are added together, their sum

will be the logarithm of the *product* of the numbers to which they belong: thus, in the system,

Logarithms	0	1	2	3	4	5, &c.,
Numbers	1	2	4	8	16	32, &c.,

2 is the logarithm of 4, 3 is the logarithm of 8, and 5, the sum of 2 and 3, is the logarithm of 32, the product of 4 and 8.

If any one of the logarithms be substracted from another, their *difference* will be the logarithm of the *quotient* resulting from dividing the second of the corresponding numbers by the first: thus, in the system,

Logarithms	0	3	6	9	12	15, &c.,
Numbers	1	5	25	125	625	3125, &c.,

9 is the logarithm of 125, 15 is the logarithm of 3125, and 6, the defect of 9 from 15, is the logarithm of 25, the quotient of 3125 divided by 125.

If any one of the logarithms be multiplied by a number, the product will be the logarithm of that power of the corresponding number which is denoted by the multiplier; and if any one of the logarithms be divided by a number, the quotient will be the logarithm of that root of the corresponding number which is denoted by the divisor: thus, in the system to which the table of logarithms is computed,

Logarithms	0	1	2	3	4	5, &c.,
Numbers	1	10	100	1000	10000	100000, &c.,

2 is the logarithm of 100, and 2 multiplied by 2 is 4, the logarithm of 10000, which is the square or second power of 100. Again, 6 is the logarithm of 1000000, and 6 divided by 3 is 2, which is the logarithm of 100, the cube root of 1000000.

Thus, then, the addition of logarithms answers to multiplication of the corresponding numbers; subtraction, to division; multiplication, to involution; and division, to evolution.

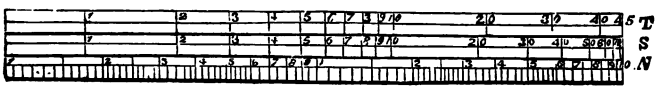
Logarithms were invented by John Napier, Baron of Merchiston, and were first published in 1614. In 1620 Edmund Gunter, then Gresham Professor, inventor of the Sector, laid them down on a scale, by the application to which of a pair of compasses arithmetical questions might be solved instrumentally.

The difficulty that formerly existed of laying down the

logarithmic divisions correctly considerably marred their utility; but in the present day rules are engine-divided, and most useful instruments for computations of all kinds are produced.

Besides lines graduated to form a scale of logarithms of numbers, others are so graduated as to represent the logarithms of the sines, tangents, &c., of the degrees and minutes in a quadrant; and to these are added, for the use of navigators, lines of the logarithms of the sine-rhumbs and tangent-rhumbs. All these are called GUNTER'S LINES.

They may be constructed as follows :—

1. *To construct the Line of Logarithmic Numbers marked N.* —Having fixed upon a convenient length for the entire scale, bisect it, and figure it 1 at the commencement on the left hand, 1 again in the middle, and 10 at the end. The half line, then, is taken for unity, or the logarithm of 10, and, consequently, the whole line represents 2, or the logarithm of 100. The half line being now divided into 1,000 equal parts, the lengths corresponding to the three first figures of the logarithms of 2, 3, &c., up to 9, as found in the common table of logarithms, may be taken, and set off from the 1 at the commencement of the line for the logarithms of 2, 3, &c., to 9, and again from the 1 at the middle of the line for the logarithms of 20, 30, &c., to 90. The divisions thus formed are to be subdivided by setting off, in the same manner, the three first figures of the logarithms of 1·1, 1·2, 1·3, &c., to 1·9; of 2·1, 2·2, 2·3, &c., to 2·9, and so on, each of the primary divisions being thus subdivided into ten; and these again are to be subdivided each into ten, or five, or two, as the length of the secondary divisions may admit, by setting off the logarithms of 1·11, 1·12, 1·13, &c.; or of 1·12, 1·14, &c.; or of 1·15, 1·25, &c.; and the scale is completed.

2. *To construct the Line of Logarithmic Sines marked S.*— The whole length of the scale is taken as the logarithm of the radius, and, since this extent upon the line of numbers

represents 2, or the logarithm of 100, it follows that the line of sines is to be a scale of the logarithms of the sines, to radius 100, of which the logarithm is 2; whereas the logarithmic table of sines is set down to a radius, of which the logarithm is 10. By taking 8, then, from each of the tabulated values of the logarithmic sines, we should obtain the logarithmic sines to radius 100, and the three first figures of these reduced values are to be set off from the left hand towards the right; 1st, for every 10 degrees, then for every degree, and then for every half degree, every 10 minutes, and every 5 minutes, as far as the length of the several primary divisions will admit. The line is then numbered 1, 2, 3, &c., at every degree to 10; and afterwards 20, 30, 40, &c., at every ten degrees to 90, which stands at the extreme right, since sine 90° equals radius.

The tabulated logarithmic sine of 34′ 23″, being 8·0000669, will coincide, or nearly so, with the zero point upon our scale, and consequently angles smaller than this cannot be taken off from the sines. This remark applies equally to the line of tangents, the tabulated logarithmic tangent of 34′ 23″ being 8·0000886.

By taking the extents backwards from right to left, and reckoning them as forward distances, the line of sines becomes a line of cosecants,* giving us, in fact, the excesses of the logarithmic cosecants above the logarithmic radius; and, by taking the complements of the required angles, the line of sines becomes a line of cosines when measured forwards from left to right, and a line of secants when measured backwards from right to left.

3. *To construct the Line of Logarithmic Tangents marked T.* —8 being taken from each of the tabulated values of the logarithmic tangents up to 45°, the extents corresponding to these values are to be set off upon the scale, and numbered from left to right, in a similar manner to that in which the logarithmic sines were set off and numbered upon the line of logarithmic sines. The logarithmic tangent of 45°, extends

* Cosecant $= \frac{r^2}{\text{sin.}}$, and sec. $= \frac{r^2}{\text{cos.}}$;
and, therefore, log. cosecant = 2 log. rad. — log. sine;
or, log. cosecant — log. rad. = log. rad. — log. sine;
and log. secant = 2 log. rad. — log. cos.;
or, log. secant — log. rad. = log. rad. — log. cos.

to the extreme right of the scale, coinciding in extent with the sine of 90°, since tangent 45° equals radius; and the logarithmic tangents of the angles from 45° to 90° are measured backwards from the extreme right to the complement of the angle required, these extents giving us, in fact, the excesses of the logarithmic tangents sought above the logarithmic radius.* When, then, the angle is greater than 45°, the distance from the radius to the angle, though measured backwards upon the scale, must be reckoned a forward distance, and *vice versâ*.

The lines of logarithmic sine-rhumbs, marked S.R., and tangent-rhumbs, marked T.R., are formed in the same way as the lines of logarithmic sines and tangents, but are set off for the angles corresponding to the points and quarter points of the compass, instead of for degrees and minutes.

We shall now proceed to explain the uses of Gunter's lines.

1. *The Line of Logarithmic Numbers.*—The primary divisions upon this line, as explained in its construction, represent the logarithms of all the integers from 1 to 100, while the extents to the first subdivisions will indicate tenths of an unit from the beginning of the scale to 1 in the middle, and units from 1 in the middle to 10 at the end, where the figures 2, 3, &c., stand for 20, 30, &c., as has been explained in the construction. If any of the subdivisions be further subdivided into ten parts, each of these last divisions will indicate hundredths of an unit from 1 at the beginning to 1 in the middle, and tenths of an unit from 1 in the middle to 10 at the end. By this line the multiplication and division of numbers of any denomination either whole or fractional may be readily accomplished, questions in proportion solved, and all operations approximatively performed with great rapidity, which can be performed by the common table of logarithms; but the numbers sought must always be supposed to be divided or multiplied by 10 as many times as will reduce them to the numbers, the logarithms of which are actually set off upon the line of numbers, and these tens must be mentally accounted for in the result.

* $\text{Tan.} = \frac{r^2}{\text{cotan.}} = \frac{r^2}{\text{tan. of compt.}}$;

$\therefore$ log. tan. = 2 log. rad. — log. tan. of compt.;
or, log. tan. — log. rad. = log. rad — log. tan. of compt.

Multiplication is performed by extending from 1 on the left to the multiplier; and this extent will reach forwards from the multiplicand to the product. Thus, if 125 were given to be multiplied by 250, extend the compasses from 1 at the left hand to midway between the second and third subdivision, in the first primary division from 1 to 2, for the 125. This extent is really the logarithm of 1·25. Set off this extent towards the right from the fifth subdivision after the primary division marked 2, which is taken to represent the logarithm of 250, but is really the logarithm of 2·5, and the compasses will reach to a quarter of the next subdivision beyond the first subdivision after the primary division marked 3. The extent to this point is really the logarithm of 3·125; but in this case it represents the number 31250, because two powers of ten have been cast out from both the multiplier and multiplicand, and therefore the product must be multiplied by the product of four tens, or ten thousand; or, in other words, the first figure of the product must be reckoned as so many tens of thousands.

Division, being the reverse of multiplication, is performed by extending from 1 on the left to the divisor; and this extent will reach backwards from the dividend to the quotient. Thus, if 31250 were to be divided by 250, extend the compasses from 1 on the left to 2·5, and this extent will reach backwards from 3·125 to 1·25. Then, since the divisor contained 2 powers of ten and the dividend 4, the quotient must contain 2, and therefore the result is 125.

Proportion being performed by multiplication and division, extend the compasses from the first term to the second, and this extent will reach from the third to the fourth, taking care to measure in the same direction, so that, if the first be greater than the second, the third may be greater than the fourth, and *vice versâ*. *Example.*—If the diameter of a circle be 7 inches, and the circumference 22, what is the circumference of another circle, the diameter of which is ten? Extend the compasses from 7 to 10, and this extent will reach from 22 to 31·4, or nearly 31½ inches, the circumference required.

The same thing may also be performed by extending from the first term to the third, and this extent will reach from the third term to the fourth (Euc. v., prop. 16). Thus, the extent from 7 to 22 will reach from 10 to 31·4, as before.

To measure a Superficies, extend from 1 to either the

breadth or length, both being reduced to the same denomination, and this extent will reach forwards from the length or breadth to the superficial content. *Example.*—Required the superficial content of a plank 27 feet long by 15 inches broad. Extend from 1 to 1·25, for 15 inches equals 1·25 feet, and this extent will reach from 27 feet to 33·75 feet, the superficial content required.

Second Method.—Extend from 12 to the number of inches in the breadth, and this extent will reach in the same direction from the number of feet in the length to the number of square feet in the superficial content. Thus the extent forwards from 12 to 15 will reach forwards from 27 to 33·75, as before; while the extent backwards from 12 to 9 will reach backwards from 27 to 20·25 or 20¼, showing the superficial content of a plank 27 feet long by 9 inches broad to be 20·25, or 20¼ feet.

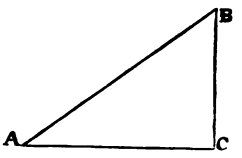
To measure a Solid Content.—The breadth, depth, and length being all reduced to the same denomination, extend from 1 to either the breadth or depth, and this extent will reach from the depth or breadth forwards to a fourth number, which will represent the superficial content of the section at the place measured: then, if the breadth and depth be the same throughout the entire length, the extent from 1 to the superficial content thus found will reach forwards from the length to the solid content. *Example.*—What is the solid content of a pillar 1 foot 3 inches square, and 21 feet 9 inches long? The extent from 1 to 1·25 reaches forward from 1·25 to 1·56, the superficial content of a section of the pillar; and the extent from 1 to 1·56 reaches from 21·75 to 34, or more accurately to 33·93, the solid content in feet.*

2. *The Lines of Logarithmic Sines and Tangents.*—These lines are generally used, in connection with the line of numbers, for solving all proportions in which any of the terms are functions of angles, as sines, tangents, &c., and, in fact, all questions in which such quantities appear as factors or divisors. We will exemplify their use by giving the solution, by their aid, of the several cases of right-angled trigonometry.

* The uses of the line of logarithmic numbers will be more fully appreciated after studying the slide-rule, to be presently described; but the student will, we hope, from what he sees here, perceive that it can be readily applied to every case of mensuration, and, in short, to almost every arithmetical operation. Additions and subtractions, however, cannot be performed by it.

Case 1*. The hypothenuse and angles being given, to find the perpendicular and base.

NOTE.—One acute angle of a right-angled triangle being the complement of the other, or the sum of the two acute angles being equal to 90°, when one of the acute angles is given, the other is also given.



Solution.—Extend the compass from 90°, or radius, on the line of sines to the number of degrees in either of the acute angles, and that extent will reach backwards, on the line of numbers, from the hypothenuse to the side opposite this angle. *Example.*—Given the hypothenuse A B = 250, and the angle A = 35° 30′

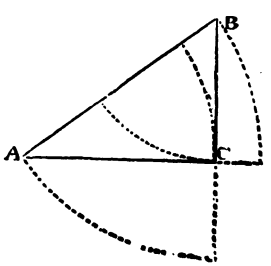
	90° 0′
Extend from 90° to 35° 30′ on the line of sines, and	B A C = 35 30
this extent will reach from 250 to 145 on the line	A B C = 54 30
of numbers	∴ B C = 145
Extend from 90° to 54° 30′ on the line of sines, and	
this extent will reach from 250 to 203·5 on the line	
of numbers	∴ A C = 203·5

Case 2. The angles and one side being given, to find the hypothenuse and the other side.

Solution.—Extend from the angle opposite the given side to 90°, or radius, on the line of sines, and this extent will reach forwards from the given side to the hypothenuse on the line of numbers. Again, extend from the angle opposite the given side to the angle opposite the required side, and this extent will reach in the same direction on the line of numbers, from

* These cases are, in fact, the solutions, by the aid of Gunter's lines, of the following proportions, which will be obvious to the student upon inspection of the accompanying figure.

Rad. : sin. A : : AB : BC Rad. : sin. B : : AB : AC	Case 1.
Sin. B : rad. : : AC : AB Sin. B : sin. A : : AC : BC Rad. : tan. A : : AC : BC	Case 2.
AB : AC : : rad. : sin. B Rad. : sin. A : : AB : BC	Case 3.
AC : BC : : rad. : tan. A BC : AC : : rad. : tan. B *Sin. A : rad. : :* BC : AB	Case 4.



the given side to the required side. Or, extend from radius, or 45°, on the line of tangents, to the angle opposite the required side, and the extent will reach, in the same direction on the line of numbers, from the given side to the required side; recollecting that, when the angle is greater than 45°, the extent is to be taken on the scale backwards from rad. or 45° to the complement of the angle, but is to be reckoned a forward distance, the logarithmic tangents of angles greater than 45° exceeding the logarithmic tangents of 45°, or radius, by as much as the logarithmic tangents of their complements fall short of it.

Example.—Given the angle A = 35° 30′ and side A C = 203·5.

	90° 0′
Extend from 54° 30′ to 90°, or rad., upon the line of sines, and this extent will reach forwards from 203·5 to 250 on the line of numbers	BAC = 35 30 ABC = 54 30 ∴ AB = 250
Again, extend from 54° 30′ backwards to 35° 30′, on the line of sines, and this extent will reach backwards from 203·5 to 145 on the line of numbers .	∴ BC = 145
Or extend backwards from 45°, rad., to 35° 30′ on the line of tangents, and this extent will reach backwards from 203·5 to 145 on the line of numbers, as before.*	

Case 3. The hypothenuse and one side being given, to find the angles and the other side.

Solution.—Extend from the hypothenuse to the given side on the line of numbers, and this extent will reach from 90 or rad. to the angle opposite the given side upon the line of sines. The other angle is the complement of this. Extend upon the line of sines from the rad. to the angle last found, which is opposite the required side, and this extent will reach from the hypothenuse to the required side. *Example.*—Given the hypothenuse AB = 250, and the side A C = 203·5.

	90° 0′
Extend backwards from 250 to 203·5 on the line of numbers, and this extent will reach from 90° to 54° 30′ on the line of sines	∴ ABC = 54 30
Extend from 90° to 35° 30′ on the line of sines, and this extent will reach backwards from 250 to 145 on the line of numbers	BAC = 35 30 ∴ BC = 145

* The property that tan. : rad. : : sine : cosine, may be made a test of the accuracy of the scale, since the distance from 45 to any angle upon the line of tangents ought to be the same as the distance from the angle to its complement upon the line of sines.

Case 4. The two sides being given, to find the angles and the hypothenuse.

Solution.—Extend from one side to the other upon the line of numbers, and this extent will reach backwards upon the line of tangents from rad. to the least angle, and to the same point, considered as a forward distance, representing the greatest angle, which is the complement of the least. Again, extend on the line of sines from one of the angles just found to rad., and this extent will reach from the side opposite the angle taken to the hypothenuse. *Example.*— Given A C = 203·5 and B C = 145.

Extend backwards upon the line of numbers from 203·5 to 145, and this extent will reach backwards from 45° to 35° 30′ on the line of tangents, which is the angle opposite the side 145	90° 0′ ∴ B A C = 35 30
If we measure forwards from 145 to 203·5, then from rad. to 35° 30′ is to be considered a forward distance, and the angle to be taken as the complement of 35° 30′, that is, 54° 30′, which is the angle opposite the side 203·5	∴ A B C = 54 30
Again, extend from 35° 30′ to 90° on the line of sines, and this extent will reach from 145 to 250 upon the line of numbers	∴ A B = 250

GUNTER'S SCALE.

Gunter's scale, for the use of navigators, which still goes by the name of its inventor, the Gresham Professor of 1619, consists of a rule, generally 2 feet in length, and about 1¾ inches broad, having one edge bevelled to answer the purpose of a straight-edge. On one side of it are placed lines of logarithmic numbers, from 1 to 100, marked N U M, of logarithmic sines, versed sines and tangents, marked respectively S I N, V S, and T A N, and of sine rhumbs and tangent rhumbs, marked S R and T R. Upon the same side are also placed a scale of meridional parts and a corresponding scale of equal parts. These latter scales are used in the construction of a Mercator's chart. On the other face of the instrument are placed, at the top edge, a scale of inches, forming an ordinary two-feet rule, a combined inch and half-inch diagonal scale, scales of rhumbs, chords, sines, tangents, and semitangents, and corresponding scales of rhumbs, chords, and longitudes. Several scales of equal parts are sometimes added, also a scale of 100 parts to a foot, ranging throughout the entire length of the rule, and corresponding scales of roots and cubes, the numbers on the cube line being the cubes of those on the root line under which they stand.

The construction and use of these scales have been described, with the exception of the scale of meridional parts.

In a Mercator's chart the earth is conceived to be projected on a plane surface in such a manner, that the bearings between places, and the proportions between the latitude, longitude, and nautical distance, shall be the same as those on the globe. Now, in proceeding from the equator to the poles, the lengths of the degrees of longitude diminish in the proportion of radius to cosine of the latitude, or of secant of the latitude to the radius; and as in Mercator's projection, in which the meridians are represented by parallel straight lines, the lengths of the lines representing equal differences of longitude are everywhere equal, the proportion between the true lengths of the degrees of latitude and longitude must be restored by increasing the lengths of minute portions of the meridians, in the continually increasing ratio of radius to secant of the latitude. The meridional parts for any given latitude are therefore found by adding together the products of successive minute portions of that latitude by the natural secants of the latitude of each portion; and the smaller those are taken, the more correct will be the table so formed. Constructing, then, a scale of equal parts to represent the actual lengths of degrees of latitude, a second scale having the divisions increased, as explained above, will represent the individual parts, from which the distances between the parallels of latitude on the chart may be taken off, while the distances between the meridians are taken from the corresponding scale of equal parts.

The sliding Gunter's scale has a slide working in its centre throughout its entire length, having on one of its faces lines of logarithmic numbers, and on the other lines of logarithmic sines and tangents. The advantages of this arrangement will be understood after reading the following articles upon the slide-rule; but both faces of the scale being now occupied with logarithmic lines, the numerous scales of equal parts and protracting scales, placed on the ordinary Gunter's scale, are omitted.

THE SLIDE-RULE.*

The slide-rule is an instrument containing the logarithmic lines, which have been already described, so arranged, as by means of the motion of a slide, to enable the sums and

* See also: "*The Slide-Rule, and How to Use It*," by Chas. Hoare, C.E. Price 3s. WEALE SERIES. With Slide-Rule in text.

differences of the logarithmic lengths to be at once seen without the assistance of the compass. We shall find, as we proceed, that the lines can be so arranged as to give special facilities for particular classes of questions, and hence several slide-rules are now in common use, adapted to the wants of persons engaged in different pursuits. All these rules, however, contain on one of their faces the four lines, A, B, C, D, (Plate III., Figs. 1, 2, 3). In most rules all the three lines, A, B, C, are called double lines, because the figures from 1 to 10 are contained twice in the length of the rule; and in the fourth line, D, the same figures are contained but once, and consequently the lengths upon this line, being twice the lengths denoted by the same numbers on the others, denote the logarithms of the squares of the numbers placed against the divisions.* The lines B and C are graduated along the two edges of a stick which works in a groove between the lines A and D. The lines B and C, being identical, are on some rules denoted by the single letter B or C; but both edges of the slide are still graduated, one to work with the A line, and the other with the D line. The B and C lines are mere copies of the A line.

The method of notation on the rule, and the manner of estimating any number upon it, are the same as have already been fully explained, when treating of the line of logarithmic numbers (p. 93).

When the slide is laid evenly in the groove, the divisions on A and B coincide, and the numbers on the coincident divisions are the *same;* and when the slide is in any other position, the numbers on the divisions of A are *proportional* to the numbers on the coincident divisions of B.

Also, when the slide is laid evenly in the groove, the numbers of the divisions on C are the squares of the numbers on the coincident divisions of D; and when the slide is in any other position, the numbers of the divisions on C are *proportional* to the squares of the numbers on the coincident divisions of D.

In using the A and B lines, it is immaterial whether a number is chosen upon the first or second divisions of those lines; but in ascertaining squares and square roots by means

* No advantage is obtained however by making the A line double, provided the B and C lines be so. But if the A line be made single, and equal to the whole length of the rule, the D line must be double the length of the rule, and must therefore be laid down half above *and half below a groove.*—See Coulson's Slide-Rule, page 144.

of the lines C and D, if the number of figures representing the square be odd, it must be selected from the first division of C; if even, from the second division. In extracting the square root of a number containing decimals, the number of decimals, if odd, must first be made even by the addition of a zero, and the preceding rule be then applied in the same manner as though the figures represented whole numbers.

In Coulson's rule the A line is only a single line, and the D line is laid half above and half below the slide: by this means the rule is made of only half the length for the same sized length of the graduations. This convenient arrangement presents no difficulties in the working; but the numbers on C must be considered as belonging to the first division when used with the first half of D above the slide, and to the second division when used with the second half of D below the slide.

ON THE USES OF THE A AND B LINES.

In whatever position these lines may be placed with respect to each other, the numbers in the coincident divisions represent a series of proportionals; in fact, we have here an instrument exhibiting at once to the eye the solutions of all problems in the rule of three. In its application, then, three terms of a proportion are always given to find a fourth. In the cases of multiplication and division, one of these terms is unity; thus, in multiplication, 1 : either of the factors : : the remaining factor : the product; and in division, divisor : 1 : : dividend : quotient, or divisor : dividend : : 1 : quotient.

We proceed to give a few examples of the application of the lines A and B.

Problem 1. *To multiply two Numbers together.*—Set 1 on A to the multiplier on B; and against the multiplicand on A will be found the required product on B. *Example.*—To multiply 33 by 23. Set 1 on A to 2·3 on B, and against 3·3 on A will be found 7·59 B; 759 is therefore the product required.

B 23	759
A 1	33

NOTE.—It is to be remarked that, in the solution of questions by the slide rule, the figures representing the result are alone given by the rule, and the power of ten involved in the result must be mentally supplied by the operator: thus, in the above example, each of the factors containing one power of ten, the product contains two powers of ten or hundreds; had the factors been 2·3 and 330, both the operation and the

result would have been the same; but had the factors been 2·3 and 3·3, or 230 and 300, the operations would have been the same, but the results would have been 7·59 and 75900, respectively. It is also to be noted that, provided the tens in the result be duly supplied, either ends of the lines A or B may be taken for the 1, or the division marked 1 in the middle may be used, when the lines are double, or numbered twice, from 1 to 10.

The subject of numeration upon the rule is therefore one of considerable importance.

NUMERATION ON THE A AND B LINES.

In some treatises upon the slide-rule that we have seen, great and unnecessary difficulties have been introduced into the subject of numeration on the rule, and it appears to us that this has in a great measure arisen from treating as necessary that which is, in fact, superfluous, and, inasmuch as it has led to perplexity, injurious, viz., the laying down the lines A, B, and C twice over, from 1 to 10. It is, in fact, only desirable that either the line A or the line on the slide should be so laid down, and in this case the rule of numeration would be extremely simple. In fact, as already stated, it is only the making the A line, as well as the lines on the slides, double, that has created any difficulty in the matter. When they are so, the same numbers are always coincident on both sections of the lines; but we should advise the learner, although supplied with a rule having the A line laid down twice, to use at first one part of it only, until he thoroughly understands the use of the rule. Making use, then, of only one section of the A line, the rule for numeration will be as follows:—let the first term of the proportion be taken on A, so that the fourth or sought term is on B, then, if the two numbers on the B line coinciding with two on the A line be both on one section of the B line, the difference between the numbers of integral places of the numbers on the B line must be the same as that for the numbers on the A line; but when the numbers coinciding with two numbers on the A line are on different sections of the B line, the difference between the numbers of integral places on the B line being first considered to be the same as those on the A line, as in the former case, the number of integral places in the fourth or sought term must be increased by one, if it be on the second, or right-hand, section of B, or diminished by one if it be on the first, or left-hand, section. Thus, in the example to Problem 1, the 23 on the line B being set against 1 on A, the

33 on A, taken on the same section as the 1 (the other section on this line being altogether neglected), comes against 759 on the first section of B, and since the number of integral places in 33 is one more than the number in 1, the number in the 759 must be one more than the number in 23, so that the answer is 759. Had the second number on A been 3·3, the integral places in 759 must have been the same as in the multiplier 23, so that if this had been ·23, 2·3, or 23, the number sought would have been respectively ·759, 7·59, or 75·9. Had the second number on A been 330, having two more integral places than 1, the number sought would have had two more integral places than the multiplier, so that if this had been 230, the product would have been 75900. If the problem had been to multiply 43 by 33, the 43 on the first, or left-hand, section of B being set against the 1 on A, the 33 on A will come against the 1419 on the second, or right-hand, section of B, and the number of integral places in 33 being one more than the number in 1, the number in 1419 must, on this account, be one more than the number 43, and again another one more because it comes on the right-hand section of B, so that the answer would be 1419.

In the following examples one section only of the A line is made use of.

Problem 2. *To divide one Number by another.*—Against the divisor on A set the 1 on B, and against the dividend on A will be found the required quotient on B. *Example.*—To divide 216 by 24. Against 24 on A set 1 on B, and against 216 on A will be found 9 on B, which is the quotient required.

B	9	1
A	216	24

In this example the number of integral places in 216 being one more than the number in 24, the number in the result, if it came on the same section of the B line as the given term 1, would be one more than the number in this term, so that the result would in that case contain two integral figures; but, the 1 being taken on the right-hand section of the B line, the result, coming on the left-hand section, must on this account have its number of integral places diminished by one, so that it will contain only the single integral figure 9.

Second Method.—Against the divisor on A set the dividend on B, and against the 1 on A will be found the required quotient on B. *Example.*—To divide 551 by 29. Against

29 on A set 551 on B, and against 1 on A will be found 19, the required quotient on B.

B 19	551
A 1	29

Here the numbers on the B line being both on the same section of it, and the number of integral figures in the 1 on the A line being one less than the number in the 29 on the same line, the number in the result 19 on the line B is to be one less than the number in the 551 on the same line.

Problem 3. *To find a Fourth Proportional to three given Numbers.*—Set the third term on B to the first term on A, and against the second term on A will be found the required fourth term on B. Or, against the first term on A set the second term on B, and against the third term on A will be found the required fourth term on B. *Example.*—To find a fourth proportional to the three numbers, $3\frac{1}{2}$, 11, and 14. Against $3\frac{1}{2}$ or 3·5 on A set 11 on B, and against 14 on A will be found, on B, 44, the fourth proportional required.

B 44	11
A 14	3·5

Or against 3·5 on A set 14 on B, and against 11 on A will be found 44 on B, as before.

B 44	14
A 11	3·5

The number of integral figures in 14 or 11 on the A line is one more than the number in 3·5 on the same line, and consequently the number in the result would be one more than the number in 11 or 14, if it came on the same section of the line B as this term; but the numbers on the B line being on different sections of it, the number of integral places in the result which comes on the left-hand section must on this account be reduced by one, so that instead of three integral figures there must be two only.

Problem 4. *To find a Third Proportional to two given Numbers.*—This is the same problem as the preceding, repeating the second number for the third term of the proportion. *Example.*—To find a third proportional to the two numbers $3\frac{1}{2}$ and 11. This is to find a fourth proportional to the three *numbers, $3\frac{1}{2}$, 11,* and 11. Set, therefore, $3\frac{1}{2}$ or 3·5 on A to

11 on B, and against 11 on A will be found, on B, 34·6, the third proportional required.

B 34·6	11
A 11	3·6

Problem 5. *To square a given Number.*—Against 1 on A set the given number on B, and against the given number on A will be found its square upon B. *Example.*—Required the square of 23. Against 1 on A to 23 on B, and against 23 on A will be found its square, 529, on B.

A 1	23
B 23	529

The numbers on the B line being here both on the same section of it, and the number of integral figures in the 23 on the A line being one more than the number in the 1 on the same line, the number in the result on the B line must also be one more than the number in the 23 on this line.

Problem 6. *To find the Area of a Board or Plank. First Method.*—Set 12 on A to the mean breadth in inches on B, and against the length in feet on A will be found upon B the required area in feet and decimals of a foot. If the plank taper regularly, the mean breadth is half the sum of the extreme breadths; but, if the plank be irregular, several breadths should be measured at equal distances from each other, and their sum divided by their number may be taken as the mean breadth. In the latter case, however, greater accuracy would be obtained by finding separately the areas of portions of the plank, and adding them together for the whole area, or by the following. *Second Method.*—Take the measure in inches of several breadths at equal distances from each other, and add together half the two extreme breadths, and the sum of all the intermediate breadths. Set 12 on A to the sum thus found upon B, and against the distance in feet at which the breadths have been measured upon A will be found upon B the required area in feet and decimals of a foot. *Example* 1.—A board, 15 feet long, being 14 inches broad at one end, and 8 inches broad at the other, required its area. The mean breadth is 11 inches, half the sum of 8 and 14. Set, then, 12 on A against 11 on B, and against 15 on A will be found upon B 13·75 or 13¾ feet, the area required.

B 11	13·75
A 12	15

Example 2.—An irregular board, 18 feet long, being 7 inches broad at one extremity, 11 inches broad at the other, and the intermediate breadths at each 3 feet of the length being 13 inches, 25 inches, 23 inches, 32 inches, and 22 inches, required its area. By the first method, the sum of the seven breadths divided by 7, gives 19 inches for the mean breadth; and, setting 12 on A against 19 on B, against 18 on A will be found upon B 28·5 or 28½ feet, the area required.

B 19	28·5
A 12	18

By the second method, half of the two extreme breadths added to the intermediate breadths, gives the sum, 124 inches; and setting 12 on A against 124 upon B, against 3 on A will be found upon B 31, the area required, a more accurate result than the preceding.

B 124	31
A 12	3

In these examples the numbers on the B line are in each case both on the same section of it, and consequently the difference in the numbers of integral figures in the terms on the B line must be the same as that for the terms on the A line.

The following example of reduction will afford a further illustration of the method of numeration we have explained.

What is the value of ·27 of a ton in cwts., qrs, lbs., and ounces?

Since 20 cwts. make 1 ton, set 20 on B to 1 on A; and then against ·27 on A is 5·4 cwts. on B.

B 20	5·4
A 1	·27

Next, since 4 qrs. make 1 cwt., set 4 on B to 1 on A; and against ·4 on A is 1·6 qrs. on B.

B 4	1·6
A 1	·4

Again, as 28 lbs. make 1 qr., set 28 on B to 1 on A; and against ·6 on A is 16·8 lbs. on B.

B 28	16·8
A 1	·6

Lastly, as 16 ozs. make 1 lb., set 16 on B to 1 on A; and against ·8 on A is 12·8 ozs. on B.

B 16	12·8
A 1	·8

Hence, ·27 of a ton is equivalent to 5 cwts. 1 qr. 16 lbs. $12\frac{8}{10}$ ozs.

In the first step of the above reduction, the two numbers on B occur on the same section of this line, and the second number on A having one integral figure less than the first number on the same line, the result, 5·4, which is the second number on B, must also have one integral figure less than 20, the first number on this line.

In the remaining steps of the reduction the two numbers on the B line are on different sections; and the results, coming on the right-hand section, must on this account have their number of integral figures increased by one; so that, instead of being one less than in the first numbers on B, they are to be the same.

It remains to consider the case of pure decimals, *i.e.*, of proper fractions decimally expressed, which consequently have no integral part. It is evident that here no integral figures can be taken away; but the insertion of any number of zeros after the decimal point must be considered as equivalent to a diminution, and the removal of any number of them as equivalent to an increase of as many integral places: thus, instead of ·21, to put ·021, ·0021, ·00021, &c., is equivalent to depriving it of one, two, three, &c., integral places; and conversely, instead of ·0021, to put ·021 or ·21 is equivalent to an increment of one or two integral places respectively.

In fact, whether a number be whole or fractional, or partly whole and partly fractional, the removal of the decimal point any number of places to the right is equivalent to increasing the number of integral figures by that number, and the removal of the decimal point any number of places to the left is equivalent to diminishing the number of integral figures by that number, the requisite number of places, when deficient, being in both cases supplied by zeros: thus, to increase by five the number of integral places in ·021, we must write 2100, the decimal point when it comes to the extreme right of a number not being expressed; and to diminish by 4 the number of integral places in 21 we must write ·0021.

Example 1.—To divide 6·3 by ·023. Against 23 on A set 1 on B, and against 6·3 on A will be found 274 on B.

B 1	274
A ·023	6·3

The numbers on B being both on the same section, and 6·3 being considered to have two more integral figures than ·023, the 274 has two more integral figures than the 1. Had the divisor been ·23, the quotient would have been 27·4, and had the divisor been 2·3, the quotient would have been 2·74.

Example. 2.—Find a fourth proportional to the three numbers 5100, 19, and 11. Against 5100 on A set 19 on B, and against 11 on A will be found ·041 on B.

B ·041	19
A 11	5100

Since 11 has two integral figures less than 5100, the result must on this account have two integral figures less than 19, *i.e.*, it must have no integral figure; but, the two numbers on B being on different sections of the line, the number of integral places in the result, which comes on the left-hand section, must be still farther reduced by one, and, as there are already none left, an equivalent operation must be performed by inserting a zero after the decimal point, making the result ·041.

Problem 7. *To find the Reciprocal of any Number.*—Against the given number on A set the 1 on the second section of B, and against the 1 on A will be found the required reciprocal on B; or set the given number taken on the first section of B against the 1 on A, and against the 1 on the second section of B will be found the required reciprocal on A. The two numbers are, in fact, mutually the reciprocals one of the other. *Example.*—To find the reciprocal of 55. Against 55 on A set 1 on B, and against 1 on A will be found the reciprocal ·0182 on B.

B ·0182	1
A 1	55

The proper numeration of the result will be given by the method already explained, or by the following simple rule. Of the two numbers mutually reciprocal, one has always an *integral part,* and the other is a pure decimal, and the

number of zeros after the decimal point in the pure decimal, is always one less than the number of integral places in the other number: thus, if the given number contain only one integral figure, the reciprocal will have no zero after the decimal point; if the given number contain two integral figures, the reciprocal will have one zero after the decimal point; and if it contain 3, 4, &c., integral figures, the reciprocal will have 2, 3, &c., zeros after the decimal point. On the other hand, if the given number be a pure decimal, and have no zero after the decimal point, the reciprocal will contain one integral figure, and if it have 1, 2, 3, &c., zeros after the decimal point, the reciprocal will contain 2, 3, 4, &c., integers.

In the rules that have been given for the use of the A and B lines, only one division of the A line has been required, and consequently these methods are applicable to every form in which the rule is manufactured, whether the A line upon it be double or single; but in explaining the uses of the C and D lines, we have to consider three different modes of construction:—1. The most usual form, in which the A line is double, or has the numbers from 1 to 10 laid down twice over on the length of the rule, while on the D line these numbers are only laid down once in the same length. 2. The form, adopted in the timber-contenting rule, and in some other rules, in which the A line is double, as in the preceding construction, and the D line is laid down once in the length of the rule, but instead of commencing at 1 and terminating at 10, it is made to commence at 4 and terminate at 40. 3. The form adopted in Coulson's rule, in which the A line is laid down only once in the length of the rule, and consequently the D line, which must occupy twice the length of the A line, is laid down, one half of it above the groove in which the slide works, and the other half below it. In all three constructions, and in all positions of the slide, the numbers on the divisions of C are *proportional* to the squares of the numbers on the coincident divisions of D.

Problem 8. *To square a given Number by the Lines* C *and* D.—In the first of the instructions just explained, the D line is numbered from 1 to 10, and, when the slide is laid evenly in the groove, the numbers on the divisions of C are the squares of the numbers on the coincident divisions of D, so that to square any number, we have merely to set the slide so that the 1 on the beginning of C coincides accurately with

the 1 upon D, and then, looking for the number on D, we shall find the square against it on C. With respect to the numeration of the result,—1. If the number to be squared, taken on D, contain any number of integral figures, its square, found upon C, will contain twice that number of integral figures if it comes on the second section of C, and one less than twice the number if it comes on the first section. 2. If the number to be squared, taken on D, be a pure decimal, whatever number of zeros it may contain after the decimal point, the square, found upon C, will contain twice that number of zeros after the decimal point if it come on the second section of C, and one more than twice that number if it come on the first section. Hence it appears that when the slide is laid evenly in the rule, the squares taken on its first section must contain either an odd number of integral figures, or an odd number of zeros after the decimal point, and the squares taken from the second section of the slide contain either an even number of integral figures, or either none or an even number of zeros after the decimal point.

Example.—To find the squares of 1·6125, 16·125, 161·25, ·16125, and ·016125.

Against 16125 on D is 26 on the *first* section of C, and therefore the square of 1·6125, 16·125, and 161·25, containing one, two, and three integral figures respectively, will be 2·6, 260, and 26000, containing one, three, and five integral figures respectively, *i.e.*, one less than double the number in their respective roots; while the squares of ·16125, and ·016125 will be ·026 and ·00026, containing after the decimal point one more than double the number of zeros in their respective roots.

C 1	26	26
D 1	16125	51

Example 2.—To find the squares of 5·1, 51, ·51, and ·051. Against 51 on D will be found 26 on the *second* section of C, and therefore the squares of 5·1 and 51, containing one and two integral figures respectively, will be 26 and 2600, containing two and four integral figures respectively, *i.e.*, double the number in their respective roots; while the squares of ·51 and ·051 will be ·26 and ·0026, containing after the decimal point double the number of zeros in their respective roots.

In the second construction of slide rule explained above, in

which the D line is numbered from 4 to 40, the following are the modes of proceeding:—

First Method.—If the number to be squared lie between 1 and 4, or 10 and 40, or 100 and 400, &c., so that its first significant digit is less than 4; set the 1 on C to 10 on D, and against the digits on D, expressing the given number, will be found on C the digits expressing the required square. Then, the square of 1 being 1, of 10, 100, of 100, 10,000, &c., and of ·1 being ·01, of ·01 being ·0001, &c., the digits upon C must be estimated at the actual values represented by them as numbered upon the scale, viz., 1, 2, &c., to 16, or at 100 times their values, from 100 up to 1600, or at 10,000 times their values from 10,000 up to 160,000, &c., or, again, at the $\frac{1}{100}$th part of these values from ·01 up to ·16, or at $\frac{1}{10,000}$th part of these values from ·0001, up to ·0016, &c., according as the highest denomination in the number to be squared is units, or tens, or hundreds, &c., or again, tenths, hundredths, &c. *Example.*—Required the square of 23. The 10 on D being set against the 1 on C, against 23 on D will be found 5·29 on C, and, the highest denominations in 23 being tens, the square required is 529. Also the squares of 2·3, 230, 2300, ·23, ·023, would be 5·29, 52,900, 5,290,000, ·0529, ·000529, respectively, the highest denominations in the proposed numbers being respectively units, hundreds, thousands, tenths, and hundredths. *Second Method.*—If the number to be squared lie between 4 and 10, or 40 and 100, or 400 and 1000, &c., so that its first significant digit is not less than 4; set the 100 on C against the 10 on D, and against the digits on D, expressing the given number, will be found on C the digits expressing the required square. *Example.*—Required the square of 51. The 100 on C being set against the 10 on D, against 5·1 on D will be found 26 on C, and, the highest denomination in 51 being tens, the square required is 2600*.

In the third construction of slide rules, in which the D line is laid down, one-half above the groove in which the slide containing the C line works, and the other half below it, when the numbers on the slide are used with the numbers on the D line above the groove, they must be considered to belong to the first section of the C line, and to its second section

* The accurate square is 2601, but the fourth figure cannot be estimated upon a foot rule. The solution, in fact, may be considered as obtained to within the 1000th part of the whole; but, if greater accuracy is required, arithmetical methods must be resorted to.

when used with the numbers below the groove. With this proviso, the methods for finding squares are the same as in the first construction of slide-rule: thus the 1 upon the C line being made to coincide accurately with the 1 upon the D line, 26 upon the C line will be found to coincide with 16125 on the D line above the groove, and with 51 below the groove. When, therefore, the decimal point is so placed, that the number of integral places, or the number of zeros after the decimal point, in the number represented by the figures 26, is odd, the number represented by these significant figures is the square of a number represented by the figures 16125; and when the number of integral places, or the number of zeros after the decimal point, in the number represented by 26, is even, it is the square of a number represented by the figures 51.

D	16125	
C	26	
D	51	

Also, when the number to be squared lies above the groove, the number of integral places in the square upon the line C is one less than double the number in the root upon D, or the number of zeros after the decimal point is one more than double the number in the root; and when the number to be squared lies below the groove, the number of integral places in the square upon C, or the number of zeros after the decimal point, is double the number in the root upon D.

Problem 9. *To extract the Square Root of a given Number.*—This problem being the converse of the preceding, set the rule in the same manner. Then in the first construction of rule, if the given number have an odd number of integral figures or of zeros after the decimal point, take it upon the first section of C, and the figures of the root will be found against it on D, and adding one to the number of integral places, or subtracting one from the number of zeros after the decimal point, half the sum, or remainder will give the number of integral places, or of zeros after the decimal point in the root; but if the given number have an even number of integral figures or of zeros after the decimal point, take it upon the second section of C, and half the number of these integral places or zeros will give the number of integral places or of zeros in the root found against it on D.

Example 1.—To find the square roots of 260, and ·00026.

Take 26 on the first section of C, and against it on D will be found 16125; then adding one to the integral places in 260, and subtracting one from the zeros in ·00026, we have four integral places and two zeros respectively, and, taking the halves of these, we have two integral places and one zero respectively for the roots, which are, therefore, 16·125 and ·016125.

Example 2.—Find the square roots of 26 and 000026. Take 26 on the second section of C, and against it in D will be found 51, and taking half the number of integral places in ·26, and of zeros in ·000026, we have one integral place and two zeros respectively for the roots, which are, therefore, 5·1 and ·0051.

In the second construction of the slide-rule, set the 1 on C against the 10 on D, if the given square be between 1 and 16, or 100 and 1600, or 10,000 and 160,000, &c., or again between ·01 and ·16, or ·0001 and ·0016, &c., and with the 100 on C against the 10 on D, if the given square be between 16 and 100, or 1600 and 10,000, &c., or again between ·16 and 1, or ·0016 and ·01, &c.; and then against the given number on C will stand its square root on D.

Example 1.—Required the square root of 529. The given number being between 100 and 1600, set the 1 on C against the 10 on D, and against 5·29 on C will be found 23 on D, the square root required.

Example 2.—Required the square root 2601. The given number being between 1600 and 10,000, set the 100 on C against the 10 on D, and against 26 on C will be found 5·1 on D, and 51 is therefore the root sought.

In the third construction of the slide-rule, having set the 1 upon C in exact coincidence with the 1 upon D, find the given number upon C, and if it contain an odd number of integral places or of zeros after the decimal point, the figures in the root will be found above it on the first half of D; and if it contain an even number of integral places or of zeros after the decimal point, they will be found below it on the second half of D. The numeration of the result will then be the same as for the first construction of the rule, explained above; the roots found on the first half of D, above the groove, containing half the number of integral places of those in the given number increased by one, or half the number of zeros after the decimal point of those in the given number decreased by one; and the roots found on the second half of D, below the groove, containing half the number of integral places or of zeros after the decimal point of those in the given number.

The particular cases of numeration just considered, are included in the general rules for numeration upon the C and D lines, which we proceed to explain, and which will lead us to an examination of the relative merits of the three forms of construction.

In every position of the slide, and in all these constructions, the numbers on the divisions of C are proportional to the squares of the numbers on the coincident divisions of D, and the numbers on the divisions of D are proportional to the square roots of the numbers on the coincident divisions of C: hence every problem solved upon these lines must resolve itself into finding the fourth term of a proportion in which the two first of the three given terms are either (1) the squares or (2) the square roots of the given numbers. In the former case the two first terms are taken upon D, and the third term, coincident with first term, upon C, upon which also the result is found, coincident with the second; and in the latter the two first terms are taken upon C, and the third, coincident with the first, upon D, upon which also the result is found, coincident with the second term.

In the first mode of construction, in which the D line is numbered from 1 to 10 upon the whole length of the rule, (1) if the first two given terms are squares, and therefore taken on D, and the coincident divisions upon C are upon the same section of this line, then the difference between the numbers of integral places in the two terms upon C must be made double the difference between the numbers in the two terms upon D, and if any of the terms are pure decimals, the addition of zeros after the decimal point are to be considered equivalent to the subtraction of as many integral places, and the removal of zeros after the decimal point, to the addition of as many integral places. (2.) If the first two terms are squares, and therefore taken on D, and the coincident divisions upon C are upon different sections of this line, then the difference between the numbers of integral places in the two terms upon C, being first made double the difference between the numbers in those upon D, the number of integral places in the result must be increased by one if it come on the right-hand section of C, and diminished by one if it comes on the left-hand section. (3.) If the first two terms are the square roots of two numbers, and are therefore to be taken on C, then if the difference between their numbers of integral places be *even, the same proviso* as before being made with respect to

zeros after a decimal point, these two terms must be taken on the same section of the C line, and the difference between the numbers of integral places in the two terms upon the coincident divisions of the D line must be made equal to half the difference between the numbers of those taken upon C. (4.) If the first two terms are the square roots of two numbers, and therefore to be taken on C, and the difference between their numbers of integral places be odd, these two terms must be taken on different sections of the C line; then to obtain the numeration of the result, the difference between their numbers of integral places must be diminished or increased by one, according as the term having the greater number of integral places is on the right-hand or on the left-hand section of C, and the half of the difference, thus diminished or increased, must be taken for the difference between the numbers of integral places in the coincident terms on D.

In the second construction of the rule, on which the D line is numbered from 4 to 40, throughout the entire length of the rule, when the two terms on D have their first significant digits either both less than 4, or both not less than 4, the rules for numeration are the same as in the first mode of construction; but, when one of the terms has its first digit less than 4, and the other has its first digit greater than 4, then, if the two terms coincident with those on C come both on the same section of this line, the difference between their numbers of integral places is two less or two more than twice the difference of the numbers of integral places in the two terms upon D, according as the term on the right-hand or that on the left has the greater number of integral places; but if the two terms on C come on different sections of the line, the difference between their number of integral places is one less or one more than twice the difference of the numbers of integral places in the two terms upon D, according as the term on the right hand or that on the left has the greater number of integral places.

With reference to both modes of construction just considered, it is to be remarked that, except in the case in which the slide is laid evenly in the rule, there are numbers on the D line which lie beyond one of the extremities of the C line, and *vice versâ*, and consequently that in a vast number of cases the rule is inadequate, as far as the C and D lines are concerned, to serve the purpose for which it is intended. Those questions which could not be solved on one of the rules could

most frequently be solved upon the other, but some questions could be solved upon neither of these constructions of rule.

In the first mode of construction all questions in which 1 is one of the terms to be taken upon D, and the other term upon D lies beyond the extremity of the slide, the difficulty can be got over by using the 10 at the end of the D line for 1, and obtaining the numeration of the result by making the difference between the numbers of integral places in the terms upon the C line two less or two more than twice the difference between the numbers of those on D line, according as the term on the right hand or that on the left has the greater number of integral places.

In the measurement of timber, where the dimensions of a section are given in inches and the length in feet, to find the contents in cubic feet, the failure of the first construction of rule is most conspicuous; thus, if the length were 9 feet, and the section a square, the result would be given by the proportion 12^2 : breadth^2 : : 9 : the cubical content, and the 9 on C being placed against the 12 on D, the extremity of the slide would only reach to 4 on D, and no solution would be given if the breadth were between 4 inches and 10 inches. In like manner, if the section were a cylinder, no solution would be given for diameters between $4\frac{1}{2}$ inches and 10 inches. The second form of construction has therefore been adopted in rules specially intended for this kind of work, the 12 upon the D line being in this case not far from the centre of the line, and the cases of failure to solve this particular class of problems being thereby greatly diminished.

The failures of these rules could be remedied by the addition of a third section to the C line; and in the third mode of construction, in which the D line is placed half above and half below the groove, we have, in effect, such a third section, the first half of the C line, playing the part of a first section for the numbers on D above the groove, and that of a second section for the numbers below the groove, while the second half plays the part of a second section for the numbers above the groove, and that of a third section for the number below the groove.

In making use of this third construction of the rule, as long as the two terms upon C occur on the same section, or on two adjacent sections of this line, the rules for numeration are the same as those already explained for the first construction of the rule. It remains to consider the cases in which *the two terms upon C* occur, one on the first, and the other on

the third section of this line. If, then, the two first terms are the squares of given numbers, and therefore taken on D, the third term, to be made coincident with the first term on D, is to be taken on the first or third section of C, according as this term is above or below the groove, and the fourth term sought will be found, coincident with the second term on D, on the third or first section of C. The difference between the numbers of integral places in the two terms on C being, then, first made equal to twice the difference between the numbers of those on D, the number of integral places thus found must be increased by two if the result come on the third section of C, and diminished by two if it come on the first section. Secondly, if the two first terms are square roots, and taken on C, and if the differences between their number of integral places be even, their two terms must be taken either on the same section of C, or one on the first and one on the third section. Putting then the first term on C in coincidence with the third term on D, if the second term taken on the same section of C as the first lies beyond the rule, these terms must be sought on a first and third section, and then, the difference between the numbers of integral places in the two terms being increased or diminished by two, according as the second term is on the third section or on the first, the half of the difference thus increased or diminished will give the difference between the numbers of integral places in the two terms upon D. When the second term taken on the same section as the first is coincident with a term upon D, the problem might be solved on a rule of the first mode of construction, and the rule for numeration is the same as that described for that mode of construction.

It is to be borne in mind that in all cases of terms in the form of pure decimals, the removal of zeros after the decimal point is equivalent to the addition of as many integral places, and the addition of zeros after the decimal point to a diminution of as many integral places.

It is also to be noted that throughout the whole of the rules here explained, the differences are to be understood to be taken in the same order, that is to say, the two terms on C and D having the greater numbers of integral places are to be coincident terms, and also the two having the lesser numbers of integral places.

Lastly, an equality in two numbers of integral places is to be treated as an even difference.

We now proceed to further examples of the uses of the C and D lines.

Problem 10. *To find a Mean proportional between two given Numbers.*—If x be a mean proportional between a and b, $x^2 = a\,b$, and $\therefore$ $1 : b : a : x^2$, and consequently $a : b : : a^2 : x^2$. Set, then, one of the numbers upon C to the same number on D, and against the other number on C will be found upon D the mean proportional required. *Example.*—Required a mean proportional between 4 and 49. The difference between the numbers of integral places in 4 and 49 being odd, their numbers must be taken upon different sections of the C line; then, in a rule of the first construction, the 4 upon the second section of C being set against the 4 on D, against the 49 on the first section of C will be found 14 upon D.

C 49		4
D 14		4

Again, in a rule of the second construction, the 4 upon the first section of C being set against the 4 upon D, against the 49 upon the second section of C will be found 14 upon D.

D 4		14
C 4		49

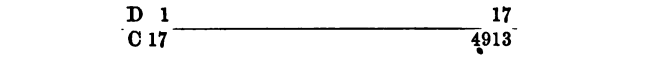
And again, in a rule of the third construction, the 4 upon C being set against the 4 on D, which is below the groove, against the 49 on C will be found above the groove 14 on D. The 4 is thus considered to belong to the second, or right-hand section of the C line, and the 49 to the first, or the left-hand section.

D		14
C	4	49
D	4	

To find the correct numeration of the result, we have to increase by one the difference between the numbers of integral places in the two terms upon the C line, and taking the half of this increased number gives us one for the difference between the numbers of integral places in the two terms upon the D line.

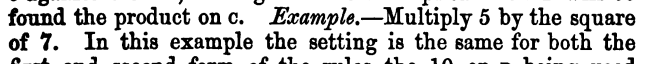
Problem 11. *To cube any given Number.*—If a represent the given number, we have the proportion $1^3 : a^3 : : a : a^3$. Set, therefore, the given number or root on C to 1 on D; and

against the root on D is the required cube on C. *Example.*—Required the cube of 17. Set 17 on C to 1 on D; and the 17 on D will reach more than a tenth beyond 49 on C, giving 4913 for the cube required.

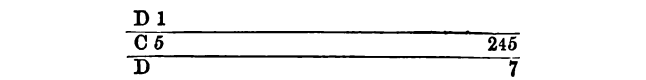


The setting of the instrument in this example is the same for all these rules, and the two terms upon C coming on the same section of this line, the difference between their numbers of integral places must be made double the difference between the numbers of the integral places in the two terms upon D.

Problem 12. *To multiply any Number by the Square of another.*—Here we have the proportion 1^2 : (multplier)^2 : : multiplicand : product. Set, therefore, the multiplicand on C against 1 on D, and against the multiplicand on D will be found the product on C. *Example.*—Multiply 5 by the square of 7. In this example the setting is the same for both the first and second form of the rules, the 10 on D being used for 1, and the two terms upon C coming upon the same section of this line. Set, then, 5 on C against 10 on D; and against 7 on D will be found 245 on C.



In a rule of the third form of construction set 5 on C against 1 on D; and against 7 on D will be found 245 on the third section of C.



The rules given for the numeration in these cases show that the difference between the number of integral places in the two terms upon C must be made two more than twice the difference between the numbers in the 1 and 7 upon D, and since this difference is nothing, the result 245 must have two more integral places than the 5.

Problem 13. *To multiply a Number by the Square Root of another.*—Here we have the proportion $\sqrt{1}$: $\sqrt{}$ (multiplier) : : multiplicand : product. Set, therefore, 1 on C to the multiplicand on D, and against the multiplier on C will be found

the product on D. *Example.*—Multiply 12 by the square root of 5. Set 1 on C against 12 on D; and against 5 on the same section of C is 26·83 on D.

D 12	26·83
C 1	5

There being no difference between the numbers of integral in the two terms taken on C, they are both taken on the same section of this line, and the setting of the instrument is the same for all three forms of the rule.

Also, there will be no difference between the numbers of integral places in the numbers on D.

Problem 14. *To divide any Number by the Square Root of another.*—Here we have the proportion $\sqrt{}$ (divisor) : $\sqrt{}$ 1 : : dividend : quotient. Set, therefore, the divisor on C against the dividend on D; and against 1 on C will be found the quotient on D. *Example.*—Divide 99 by the square root of 9. There being no difference between the numbers of integral places in the two terms taken upon C, they are to be taken on the same section of C in rules of the first and third modes of construction. Set, then, 9 on C against 99 on D; and against 1 on the same section of C will be found 33, the required quotient, on D.

C 1	9
D 33	99

In a rule of the second form, 9 on the first section of C being set against the 99 on D, the 10 at the end of the second section of C will come against the 33 on D.

D 99	33
C 9	10

Problem 15. *To divide any Number by the Square of another.* Here we have the proportion (divisor)^2 : 1^2 : : dividend : quotient. Set, therefore, the dividend on C against the divisor on D, and against 1 on D will be found the quotient on C. *Example.*—Divide 84 by the square of 4. Set 84 on the second section of C against 4 on D; and against 1 on D will be found 5·25, the required quotient, on the first section of C. We represent the setting on all three constructions of the rule.

1st construction :—

C 5·25	84
D 1	4

2nd construction :—

D 10	40
C 5·25	84

3rd construction :—

D 1		
C 5·25	84	
D	4	

The two terms upon C coming on different sections of this line, the numeration of the result, which comes on the first, or left-hand, section, is given by first making the difference between the numbers of integral places in the terms on C double that of the numbers in the terms on D, which is nothing, and then taking one integral place away.

Problem 16. *To find the Fourth Term of a Proportion of which the two First Terms are the Squares of given Numbers.*—Set the third term on C against the first term on D; and against the second term on D will be found the result on C.

Example 1.—Find the value of $\frac{8 \times 16^2}{5^2}$, or a fourth, proportional to 5^2, 16^2, and 8. In the first and third constructions of the rule, set 8 on the second section of C against 5 on D, and against 16 on D will be found 81·9, the result on the first section of C. In the second form of the rule, set 8 on the first section of C against 5 on D; and against 16 on D will be found 81·9 on the second section of C.

1st construction :—

C 81·9	8
D 16	5

2nd construction :—

D 5	16
C 8	81·9

3rd construction :—

D		16
C	8	81·9
D	5	

Example 2.—Find the value of $\frac{32^2 \times 41}{45^2}$, or a fourth proportional to 45^2, 32^2, and 41. This example cannot be solved on a rule of the second form.

In the first and third constructions, set the 41 upon one of the sections of C against the 45 upon D; and against the 32 upon D will be found upon the same section of C, the result, 20·7.

C 20·7	41
D 32	45

Example 3.—Find the value of $\frac{6{\cdot}5^2 \times 5{\cdot}2}{12^2}$, or a fourth proportional to 12^2, $6{\cdot}5^2$, and 5·2. This example cannot be solved on a rule of the first form.

In the second construction, against 12 on D set 5·2 on either section of C; and against 6·5 on D will be found the result, 1·53, on the same section of C.

D 6·5	12
C 1·53	5·2

In the third construction, against 12 on D set 5·2 on the first section of C, and against 6·5 on D will be found 1·53 on the third section of C.

D 12	
C 5·2	1·53
D	6·5

Example 4.—Find the value of $\frac{96 \times 38{\cdot}5^2}{11^2}$, or a fourth proportional to 11^2, $38{\cdot}5^2$, and 96. This example can be solved on neither of the two first constructions of the rule.

In the third construction, against 11 upon D set 96 on the first section of C; and against 38·5 upon D will be found the result, 1176, on the *third* section of C.

D 11	
C 96	1176
D	38·5

Problem 17. *To find the Fourth Term of a Proportion of which the two First Terms are the Square Roots of given Numbers.*—Set the first term on C against the third term on D; and against the second term on C will be found the fourth term

on D. *Example.*—Find the value of $\frac{4 \times \sqrt{27}}{\sqrt{12}}$, or a fourth proportional to $\sqrt{12}$, $\sqrt{27}$, and 4. Set 12 on either section of C against 4 on D; and against 27 on the same section of C will be found 6 the result, on D. The setting for this example is the same for all the three forms of rule.

D 4	6
C 12	27

When a problem arises in which the result involves the sums or difference of different quantities, the several portions of the result must be obtained separately from the rule, and then added together. *Example.*—Find the value of $\frac{40\,(24^2 + 32^2 + 59{\cdot}5^2)}{46^2}$.

$$\frac{40\ \text{C}}{46\ \text{D}} \left\{ \begin{array}{rl} 24\ \text{D} = & 10{\cdot}9\ \text{C} \\ 32\ \text{D} = & 19{\cdot}36\ \text{C} \\ 59{\cdot}5\ \text{D} = & 66{\cdot}9\ \text{C} \end{array} \right.$$

$$97{\cdot}16$$

Against 46 on D set 40 on C, and against 24, 32, and 59·5 respectively on D will be found on C the numbers 10·9, 19·36, and 66·9; and 97·16, the sum of these, will be the value required.

USE OF THE A, B, C, AND D LINES CONJOINTLY.

In the first and third forms of construction of the rule, explained above, in every position of the slide the same numbers on C and B coincide with numbers upon D and the squares of those numbers upon A. In the third construction the A and B lines will be found on the opposite face of the instrument to the C and D lines. On either of these constructions, then, the A, B, C, and D lines may be used conjointly.

Problem 18. *To divide by a Number two Numbers multiplied together, one of which is squared.*—Set the unsquared factor on B against the divisor on A, and against the squared factor on D will be found the result on C. *Example.*—Find the value of $\frac{5^2 \times 32}{6}$. Set 32 on B against 6 on A; and against 5 on D will be found 133, the required result, on C.

Solution on *First* form of Rule :—

A 6		
B 32		133
C 32		133
D		5

Solution on *Third* form of Rule :—

On one face set	B		32
	A		6
On the other face find	C 133		32
	D 5		

With regard to the numeration of the result in these conjoint solutions, it is only necessary to consider the result as always taken on B, and the number on D, if it occur on the second half of this line, as a number with twice as many integral places taken on A, and, if it occur on the first half, as a number on A with twice as many integral places less one, the rule to be applied will, then, be the same as that for solution on the A and B lines (p. 102).

Problem 19. *To divide the Product of two Numbers by the Square of a Third Number.*—Set the third or squared number on D against one of the factors on C, and against the other factor on A will be found the result on B. *Example.*—Find the value of $\frac{8 \times 16}{2{\cdot}5^2}$. Against 2·5 on D set 8 on C; and against 16 on A will be found 20·5 the result on B.

Solution on *First* form of Rule :—

D 2·5		
C 8		
B 8		20·5
A		16

Solution on *Third* form of Rule :—

On one face set	D		2·5
	C		8
On the other face find	B 20·5		8
	A 16		

THE INVERTED SLIDE.

It has been seen that, when the slide is inserted in the groove in the ordinary manner, the numbers on the line A are always proportional to the corresponding numbers on the line B, and the numbers on the line C proportional to the squares of the numbers on the line D. Now, if we invert the slide, the numbers on A and the squares of the numbers on D become reciprocally proportional to the numbers on the slide, and, as a matter of course, division becomes multiplication, and multiplication division: also the products of the corresponding numbers on A and on the slide are everywhere the same, and the products of the numbers on the slide and the squares of the numbers on D are everywhere the same.

D 2	5	10
B 09	8	2
C 09	8	2
A 4	25	100

The rules for numeration with the inverted slide are deduced from those for the direct slide, by making the differences inverse, so that the term with the greatest number of integral places on the slide coincides with the term with the lesser number of integral places on the rule, and *vice versâ*, also observing that the second section of the slide is now on the left hand, and the first section on the right hand.

EXAMPLES OF THE USE OF THE INVERTED SLIDE.

Problem 20. *To find the Reciprocal of a given Number.*— Set the inverted slide evenly in the groove, so that 10 on C coincides with 1 on A, and 1 on C with 10 on A, and any two coincident numbers will be reciprocals the one of the other, and *vice versâ*, the numeration being so arranged that the number of zeros after the decimal point in one number shall be one less than the number of integral places in the other, thus—

A 1	314	3184	10
C 1	3184	314	1

314 and 3184 being mutually coincident on the inverted slide and *the rule*, ·3184 and 3·14 are mutually reciprocal; i.e.,

$\frac{1}{3{\cdot}14} = {\cdot}3184$ and $\frac{1}{{\cdot}3184} = 3{\cdot}14$; so also 31·84 and ·0314, 314 and ·003184, &c.

Problem 21. *To multiply one Number by another.*—Set one of the numbers on the slide against the other on A, and against 1 on A will be found the product on the slide. *Example.*—Find the product of 55 by 24. Set the slide so that 24 and 55 on it coincide with 55 and 24 on A, and 1 on A will coincide with the required product, 1320, on the slide.*

C 1320	1	55	24	1320
A 1	1320	24	55	10

Problem 22. *To divide one Number by another.*—Set the slide so that the dividend and 1 are coincident, and the divisor and quotient will also be coincident. *Example.*—Divide 58 by 16. Set the slide so that 58 and 1 on A and C coincide, and 16 will coincide with the required quotient, 3·625.

C 58	3·625	16	1	58
A 1	16	3·625	58	10

Problem 23. *To find the Product of two Numbers, one of which is squared.*—Set the unsquared number on the slide against the squared number on D, and against 1 upon D will be found the product on the slide. *Example.*—Find the value of $17^2 \times 23$. Set 23 on the slide against 17 on D, and against 1 on D will be found 6647, the required product, on B.

D 1		17
B 6647		23

Problem 24. *To cube a given Number.*—Set the given number on the slide against the same number on D; and against 1 on D is the cube required. *Example.*—Find the cube of 8. Set 8 on the slide against 8 on D, and against 1 on D is 512, the required cube, on B.

D 8		10
B 8		512

Problem 25. *To find the Cube Root of a given Number.*—Set the given number on the slide against 1 on D; and look for a number on the slide standing against the same number on D, and this number will be the root required. *Example.*—Find the cube root of 7. Set 7 on the slide against 1 on D; and

* This double coincidence enables us both to set the rule and to read off the result with greater accuracy.

1·914, the required cube root, will be found coincident on the slide and on D.

D 1	1·914
B 1	1·914

Problem 26. *To square a given Number.*—Set the given number on the slide against the same number on A; and against 1 on A will be found on the slide the square required. *Example.*—Find the square of 31·5. Set 31·5 on the slide against 31·5 on A; and against 1 on A will be 992, the required square, on C.

C 992	31·5
A 1	31·5

Problem 27. *To find the Square Root of a given Number.*—Set the given number on the slide against 1 on A; and look for a number on the slide standing against the same number on A, and this number will be the root required. *Example.*—The square root of 8. Set 8 an the slide against 1 on A; and 2·828, the required square root, will be found coincident on the slide and on A.

C 8	2·828
A 1	2·828

Problem 28. *To find a Mean Proportional between two given Numbers.* Set one of the numbers on the slide against the other on A; and look for a number on the slide standing against the same number on A, and this number will be the mean proportional required. *Example.*—Find a mean proportional between 4 and 49. Set 4 on the slide against 49 on A; and 14, the required mean proportional, will be found coincident on the slide and on A.

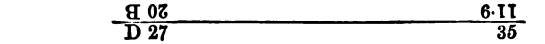
C 14	49
A 14	49

Problem 29. *To find the Fourth Term of an Inverse Proportion.*—Against the first term on A, set the third term on the slide; and against the second term on A will be found the fourth term on the slide. *Example.*—Find a number which shall have to 25 the inverse proportion of 42 to 29. Against 42 on A set 25 on C; and against 29 on A will be found 36·2, the result, on C.

C 36·2	25
A 29	42

Problem 30. *To find the Fourth Term of an Inverse Propor-*

tion the First Two Terms of which are the Squares of given Numbers.—Against the first term on D set the third term on the slide; and against the second term on D will be found the fourth term on the slide. *Example.*—Find a number which shall have to 20 the inverse proportion of 27^2 to 35^2. Against 27 on D set 20 on B; and against 35 on D will be found 11·9, the result, on B.



Problem 31. *To find the Fourth Term of an Inverse Proportion, the First Two Terms of which are the Square Roots of given Numbers.*—Set the first term on the slide against the third term on D; and against the second term on the slide will be found the fourth term on D. *Example.*—Find a number which shall have to 20 the inverse proportion of $\sqrt{27}$ to $\sqrt{35}$. Set 27 on the slide against 20 on D; and against 35 on the slide will be found 17·57, the result, on D.

THE INVERTED LINE.

As far as we have proceeded hitherto, we have been able at one operation to obtain the *product* of two numbers only, one of which may or may not be squared, divided either by unity or by a third number either squared or not; but as solids have the three dimensions of length, breadth, and thickness, and their contents are to be found by multiplying together these dimensions, and dividing by some number dependent upon the peculiar form of the solid whose content is sought, it must manifestly be a very great advantage, if, by any arrangement of the logarithmic lines, the entire result can be obtained at one operation. Now suppose we replace the D line by an inverted line, which we will call the E, or A I, line;* and, at first, let it be laid down so that its 1, 10, and 100 come against the 100, 10, and 1 of the direct line A; then, whatever be the position of the slide, laid in in the direct manner, the products of the corresponding numbers on the lines C and E are everywhere the same; and, hence, under the 100 of E, will be found on the slide the figures denoting the product of any of the two coincident numbers on the C and E lines, the

* On the timber and cubing rules the inverted lines are denoted by *E, and on Coulson's Rule* they are denoted by A I.

real product being these figures multiplied by 100. Now these figures repeated on the B line of the slide are coincident with the 1 on the A line, and hence, to multiply by another factor, we have only to look for this factor on the A line, and over it, on the B line, will be found the figures representing the continued product of the three factors; for we have, in fact, found the result to be obtained by multiplying together the three factors and dividing by 100. Thus, setting 5 on C against 60 on E, against 100 on E we have 3 on C and B, and 1 on A, and over 3 on A we have 9 on B, which is the product of $\frac{5 \times 60 \times 3}{100}$.

E	100	60	
C	3	5	
B	3		9
A	1		3

Again, let the E, or A I, line* be laid down so that any other number comes over the commencement of the A line; then, setting against any number on E, the inverted line, a second number on the slide, and taking a third number on A, we shall find on the slide, against this last number, a number which will be the product of the three numbers divided by the number on the inverted line, which falls opposite the 1 upon the A line.

EXAMPLES.

Problem 32. *To construct a Rule to give the Content in Cubic Feet of a piece of Timber or other material, when the Width and Thickness are given in Inches, and the Length in Feet.*—The width and thickness, being given in inches, must each be divided by 12 to bring them to feet, and consequently the product must be divided by 144 to bring the result to cubic feet. Let the E line, therefore, be so laid down that 144 on it may be over the 1 of the A line, and the object desired will be accomplished. *Example.*—Find the content of a piece of timber 17 feet long, 11 inches wide, and 8 inches thick. Set 8 and 11 on the slide against 11 and 8 on E, and against 17 on A will be found 10·39 cubic feet, the required content.

E	11		8
C	8		11
B		10·39	
A		17	

* See page 128.

Problem 33. *To construct a Rule to give the Content in Cubic Yards of an Excavation, when the Length, Breadth, and Depth are each given in Feet.*—Each of the dimensions must be divided by 3, to bring them to yards, and consequently the product must be divided by $3 \times 3 \times 3 = 27$, to bring it to cubic yards. Let the A I line, therefore, be so laid down that 27 on it may be over the 1 on the A line, and the object desired will be accomplished. *Example.*—Find the number of cubic yards in an excavation 9 feet deep, 20 feet broad, and 63 feet long. Set 9 on the slide against 20 on E, and against 63 on A will be found 420 cubic yards on B, the required content.

A I	20	
C	9	
B		420
A		63

Problem 34. *To construct a Rule to give the Weight, in Pounds, of a rectangular piece of Cast Iron, when the Length, Breadth, and Thickness are all given in Inches.*—A cubic inch of cast iron weighs $\frac{1}{3 \cdot 6 \, 3 \, 6}$ of a pound; and hence the content in cubic inches, divided by 3·836, gives the weight in pounds. Let the A I line, therefore, be so laid down that 3·836 on it may be over the 1 on the A line, and the object desired will be accomplished. *Example.*—Find the weight of a cast-iron plate, half an inch thick, 8 inches broad, and 48 inches long. Set 0·5 on the slide against 8 on E, and against 48 on A will be found 50 lbs. on the slide, the required weight.

A I	8	
C	·5	
B		50
A		48

NOTE.—It is immaterial on which of the lines, A, C, and E or A I, the several dimensions are taken; but it is to be observed that the result is always to be looked for on B, opposite to a dimension which has been taken on A. To prevent confusion, however, the student is advised to practise an uniform method; for example, to make the *breadth* and *thickness* coincide on C and E, and against the *length* on A will be found the content on B.

In the preceding description we have supposed the A and E lines to be laid down twice in the length of the Rule as they are on the Timber Contenting Rule (p. 149). In this rule *also, as* well as in the Cubing Rule (p. 147), the C and B lines

are both required because they are differently divided and numbered, although coincident points upon them really represent the same numbers: thus in the Timber Rule, the C line, on which inches are taken, is subdivided into fourths, while the B line is divided decimally; and in the Cubing Rule, instead of the numbers representing inches, on C are placed their equivalents in feet and inches. When, however, the lines are all divided decimally, the best arrangement is to have the A line and the inverted line laid down once only in the length of the rule, and to have only one line, B or C, on the slide, as in Coulson's Rule (p. 144). Using, then, only one section of the A line and the corresponding portion of the inverted slide, which consists of portions of two sections, all the divisions to the right of 1 or 10 belong to the first section, and the portion on the left to the second section; while on the slide the left-hand section is the first, and the right-hand section is the second. The rules for numeration are then extremely simple, viz.: add together the number of integral places in the three given terms, and subtract from the sum thus found the number of integral places in the constant divisor on the inverted line over the 1 of the A line, and the remainder will be the number of integral places in the result, if all the numbers come on first sections; but if a given term come on a second section, this number of integral placed must be diminished by one for each such term, and if the result come on the second section of B, the number must be increased by one. Hence if one of the given numbers and the result both come on a second section, the number of integral places is unaltered, *i.e.*, the same as when all the numbers are on first sections. If two of the given terms come on second sections, the integral places must be reduced by two on this account; so that if the result also come on a second section, the resulting number of integral places will still be one less than the sum of the numbers in the three terms diminished by the number in the constant divisor.

We proceed to apply these rules to the numeration of the results in the three preceding examples.

In the example to Problem 32 the sum of the numbers of integral places in the given numbers, 11, 8, and 17, is five, from which subtract three, for the number in the constant divisor 144, and there remain two, and since one of the given numbers is on a second section, for which one integral place is to be added, and the result is also on a second section for

which one is to be added, two is the number of integral places in the result.

In the example to Problem 33 the three given numbers, 9, 20, and 63 contain together five integral places, from which must be subtracted two for the number in the divisor 27, and there remain three, which, since one of the given numbers comes on a second section, and so also does the result, must be the number of integral places in the result.

In the example to Problem 34, the number of integral places in the given numbers, 0·5, 8, and 48 is three, from which subtracting one for the number in the divisor 3·836, we have two remaining, and the given numbers and result being all on first sections, two must be the number of integral places in the result.

THE TRIGONOMETRICAL SLIDE.

The trigonometrical slide contains upon it, instead of the B and C lines, lines of the logarithmic tangents and sines (p. 95) of all angles from 0° to 90°; the former of which works to the line A, and the latter to the line D; so that when the slide is laid evenly in, the numbers on A are the natural tangents, and the numbers on D the natural sines, of the degrees marked opposite to them, on the slide; and when the slide is in any position, the numbers on the A and D lines are proportional to the natural tangents and sines of those degrees. If the trigonometric lines are laid down to a radius equal to the whole length of the line of numbers, it is manifest that, since, in any position of the slide, the beginning and end of the trigonometric lines come against the same figures upon the line of numbers, supposed to be repeated, either the beginning or end of the line may be taken for radius, as may be most convenient. Sometimes the line of tangents is laid down to a radius equal to half the length of the slide only, and then either the beginning, middle, or end of the line may be taken for radius; but the middle, marked 45°, will generally be found most convenient.

In the sliding Gunter's scale the lines of logarithmic sines and tangents are laid down upon one face of the slide, and two lines of numbers on the other face, whilst the rule has upon one face a line of sines above the groove, and a line of tangents below it; and, on the other face, a line of numbers above the *groove, and a line of* sine-rhumbs below it.

There only remains one more line to be described, viz., the line of cubes, E. This line is laid down on a slide three times in the same length in which A is laid down twice, and D once; and, consequently, when this slide is laid evenly in, between the lines A and D, the numbers on D will be coincident with their cubes on the slide, and their squares upon A; and when the slide is in any other position, the numbers on E will be proportional to the cubes of the corresponding numbers on D, and the square of the numbers on E will be proportional to the cubes of the numbers on A; or the numbers on D, the square roots of the numbers on A, and the cube roots of the numbers on E, at coincident divisions, will be proportionals.

RATIOS.

When similar figures vary, their linear dimensions vary in simple proportion, but their areas vary as the squares of their linear dimensions. Thus, if the diameter of one circle be 5 times the diameter of another, the circumference of the former will also be 5 times the circumference of the latter; but its area will be 25 times the area of the latter. If then two numbers be found having the same ratio to one another as two lines in some figure, and if these two numbers be made coincident on the lines A and B, any other coincident numbers on these lines will represent the lengths of the like lines in a similar figure: thus, the ratio of the diameter to the circumference of a circle being 113 to 355, if 355 on B be set against 113 on A, then, if any diameter be taken on the line A, the corresponding circumference will be found against it on the line B, and *vice versâ*.

Again, if two numbers be found, one of which has to the square of the other the same ratio as the area of a figure to the square of one of its linear dimensions, and if the number representing the area on C be made coincident with the number representing the linear dimension on D, then any other coincident numbers will represent the linear dimension on D and the corresponding area on C of a similar figure: thus, 43 represents the area of a circle, the diameter of which is 7·4; and if 43 on C be set against 7·4 on D, and any diameter be taken on D, the corresponding area will be found on C, and *vice versâ*.

The advantage of having the ratios in whole numbers, consisting of only a few figures, is obvious, as they can be set on the rule with ease and exactness.

TABLES OF RATIOS.

TABLE I.—*Ratios relating to the Circle.*

On the Line A.*	On the Line B.*
113† to diameter.	355† to circumference.
44 „ „	39 „ side of equal square.
99 „ „	70 „ „ inscribed square.
355 „ circumference.	113 „ diameter.
39 „ „	11 „ side of equal square.
40 „ „	9 „ „ inscribed square.
70 „ side of square.	79 „ diameter of equal circle.
24 „ „	85 „ circumference „
50 „ „	76 „ side of equal equilateral triangle.
11 „ area of circle.	7 „ area of inscribed square.
452 „ „ square.	355 „ „ circle.
35 „ „	29 „ „ octagon.
57·3 „ No. of degrees	radius „ length of arc.

On the Line D.	On the Line C.
7·4 to diameter.	43 to area.
17 „ circumference.	23 „ „

TABLE II.—*Polygons within and without Circles.*

No. of Sides.	Inside Circle on Line A.*	Outside Polygon on Line B.*	Outside Circle on Line A.*	Inside Polygon on Line B.*
3	15 to diameter.	26 to side.	15 to diameter.	13 to side.
4	1 „	1 „	99 „	70 „
5	11 „	8 „	80 „	47 „
6	26 „	15 „	2 „	1 „
7	56 „	27 „	30 „	13 „
8	29 „	12 „	34 „	13 „
9	11 „	4 „	41 „	14 „
10	40 „	13 „	320 „	99 „
11	17 „	5 „	32 „	9 „
12	56 „	15 „	58 „	15 „

* The terms taken on A and B may be interchanged so as always to bring the result on B, which is desirable, in order to apply the rules for numeration we have laid down.

† That is, distance from 113 to diameter on line A is equal to distance from 355 to corresponding circumference on B; so that if the 113 on A be set against 355 on B, any diameter on A will coincide with corresponding circumference on B.

TABLE III.—*Areas of Polygons.*

No. of Sides.	On Line D.	On Line C.
3	30 to side.	390 to area.
4	1 „	1 „
5	5 „	43 „
6	5 „	65 „
7	5 „	91 „
8	6 „	174 „
9	4 „	99 „
10	6 „	277 „
11	4 „	150 „
12	4 „	179 „

TABLE IV.—*Miscellaneous Ratios.*

On Line D.	On Line C.
7·4 to diameter of sphere.	172 to surface of sphere.
17 „ circumference of sphere.	92 „ „
Side of square to its diagonal.	1 „ 2.
Side of square to diameter of circumscribing circle.	1 „ 2.
Side of cube to its diagonal.	1 „ 3.
Side of cube to diameter of circumscribing sphere.	1 „ 3.
6 seconds to time.	579 ft. / 193 yds. } to distance a body falls *in vacuo*.
80 seconds to vibrations per minute.	22 to length of pendulum in inches on inverted slide q.

EXAMPLES ON THE USE OF RATIOS.

The diameter of a circle 7 inches; what is the circumference?

A 113 — 7
B 355 — 22 inches. *Ans.*

The diameter of a circle is 9 inches; what is the side of an equal square?

A 44 — 9
B 39 — 7·97 inches. *Ans.*

What is the side of a square inscribed in the preceding circle?

A 9 — 99
B 6·36 inches. *Ans.* — 70

Supposing the circumference of the earth to be 25,000 miles, what is its diameter?

A 355	25000
B 113	7960 *Ans.*

The circumference of a circle is 8 inches; what is the side of an equal square?

A 39	8
B 11	2·25 inches. *Ans.*

What is the side of a square inserted in the preceding circle?

A 40	8
B 9	1·8 inches. *Ans.*

The side of a square is 4 inches; what is the diameter of an equal circle?

A 4	70
B 4·51 inches. *Ans.*	79

What is the circumference of the preceding circle?

A 24	4
B 85	14·2 inches. *Ans.*

The side of a square is 10 inches; what is the side of an equal equilateral triangle?

A 50	10
B 76	15·2 inches. *Ans.*

The area of a circle is 18; what is the area of the inscribed square?

A 11	18
B 7	11·45 *Ans.*

The area of a square is 18 square inches; what is the area of the inscribed circle?

A 452	18
B 355	14 sq. in. *Ans.*

What is the area of a regular octagon inscribed in the same square?

A 18	35
B 14·9 sq. in. Ans.	29

The radius of a circle is 9 inches; what is the length of an arc of it containing 32 degrees?

A 32	57·3
B 5 inches. *Ans.*	9

The diameter of a circle is 5 inches; what is its area?

C 19·63 sq. in. *Ans.*	43
D 5	7·4

The circumference of a circle is 12 inches; what is its area?

C 11·46 sq. in. *Ans.*	23
D 12	17

The diameter of a circle is 12 inches; what is the side of the equilateral triangle described about it?

A 12	15
B 20·8 in. *Ans.*	26

What is the side of a regular pentagon inscribed within the same circle?

A 12	80
B 7·05 in. *Ans.*	47

The side of an equilateral triangle is 1; what is its area?

C ·433 *Ans.*	390
D 1	30

The side of an octagon is 5 feet; what is its area?

C 121 sq. ft. *Ans.*	174
D 5	6

The circumference of a sphere is 12 inches; what is its surface?

C 45·8 sq. in. *Ans.*	92
D 12	17

The side of a cube is 7 inches; what is the length of its diagonal?

C 3	1
D 12·12 in. *Ans.*	7

What is the length of a pendulum making 60 vibrations per minute?

B 39·2	22	39·2 *Ans.*
D 60	80	

DIVISORS AND GAUGE POINTS.

We have already seen that any person, whose occupation requires him to make calculations in which the same number constantly appears as a divisor, may have a rule constructed with an inverted line, to perform with facility this particular class of computations. For general purposes, however, recourse must still be had to the A, B, C, D lines; and as the formulæ for many surfaces, and almost all solids, require the use of the D line, it is far more convenient to compute the square roots of the divisor, and take these roots on the D line, than to take the divisors on the A line. The points so taken on the D line are called gauge points, and it is manifest that, when the D line commences with unity, the gauge points on D are exactly opposite the divisors on A, so that in this case the slide is at the same time set to a gauge point and the corresponding divisor, and, therefore, except as a matter of convenience, it would be immaterial whether gauge points or divisors were made use of. The most useful gauge points are usually marked upon the rule with brass pins.

It is not necessary to register a table of divisors, since setting the C line to a gauge point on D also sets the B line to the divisor on A.*

Denoting by □ G and ○ G the square and circular gauge points for areas and surfaces, the following table exhibits their values:—

Dimensions in	Surfaces in	□ G.	○ G.
Inches.....	Square inches	1	1·128
„	„ feet.....	12	13·54
„	„ yards.....	36	40·62
Feet.....	„ „	3	3·385
„	„ rods	16·5	18·62
Links	„ „	25	28·2
Yards	„ „	5·5	6·206
„	„ acres	69·57	78·5
Chains.....	„ „	3·162	3·567

The following diagrams represent computations of areas by means of the above gauge points :—

* On rules with the D line laid down half above and half below the groove, the rule must be turned over, and the B line on the opposite *face is set to the divisor.*

Square	C 1	area
	D □ G	side
Parallelogram	A	height
	B	area
	C base	
	D □ G	
Triangle	A	height
	B	area
	C ½ base	
	D □ G	
Parabola	A	height
	B	area
	C ⅔ base	
	D □ G	
Circle	C 1	area
	D ○ G	diameter
Ellipse	A	other axis
	B	area
	C one axis	
	D ○ G	
Cycloid	C 3	area
	D ○ G	diameter of generating circle
Prism or cylinder	A	height*
	B	surface
	C perimeter	
	D □ G	
Pyramid or cone	A	slant height
	B	surface†
	C ½ perimeter	
	D □ G	
Sphere	C 4	surface
	D ○ G	diameter

* This will not include the areas of the ends, the rule for finding which will vary with their form. The diagram in the text will give the whole surface for a square prism if the height be increased by the eighth part of the perimeter, and for a cylinder if the height be increased by the radius.

† This does not include the area of the base. It will be included if the slant height be increased by the eighth part of the perimeter for a square pyramid, and by the radius for a cone.

Spherical zone

A	diameter
B	area
C 4 height	
D ○ G	

EXAMPLES.

The side of a square is 34 inches; what is its area in square feet?

C 1	8·03 sq. ft. *Ans.*
D 12	34 in.

A piece of land measures 95 links by 70; how many square rods does it contain?

A	95 links.
B	10·61 sq. rods. *Ans.*
C 70 links	
D 25	

The diameter of a circle is 17 inches; how many square feet does it contain?

C 1	1·576 sq. ft. *Ans.*
D 13·54	17 in.

TABLE OF GAUGE POINTS FOR SOLIDS.

Dimensions all taken in inches.

Contents in	□ G.	○ G.	Contents in lbs.	Specific Gravity.	□ G.	○ G.
Cubic inches	1	1·128	Platinum.....	21·45	1·135	1·28
,, feet	41·57	46·9	Standard gold...	17·61	1·252	1·412
Pints	5·88	6·64	Mercury	13·58	1·427	1·61
Gallons	16·65	18·79	Lead.....	11·35	1·56	1 76
Bushels	47·09	53·14	Standard silver.	10·2	1·646	1·857
Pounds of tallow ...	5·5	6·2	Copper.....	8·33	1·822	2·055
,, hot soap .	5·29	5·97	Brass, cast	8·3	1·825	2·059
,, cold ,, ...	5·21	5·88	Cast iron	7·21	1·958	2·21
,, flint glass	2·94	3·316				
,, plate ,,	3·36	3·79				

The following formulæ and diagrams describe the computation of contents by means of the above gauge points:—

Square prism $= \frac{l s^2}{\square G}$

C length	content
D □ G	side

Square pyramid $= \frac{\frac{1}{3} l s^2}{\square G}$

C ⅓ length	content
D □ G	side

Cylinder $= \frac{l d^2}{\bigcirc G}$

C length	content
D ○ G	diameter

Cone $= \frac{\frac{1}{3}\, l\, d^2}{\bigcirc\ G}$	C $\frac{1}{3}$ length		content
	D $\bigcirc$ G		diameter
Sphere $= \frac{\frac{2}{3}\, d\, d^2}{\bigcirc\ G}$	C $\frac{2}{3}$ diameter		content
	D $\bigcirc$ G		diameter
Spheroid $= \frac{\frac{2}{3}\, f\, v^2}{\bigcirc\ G}$	C $\frac{2}{3}$ fixed axis		content
	D $\bigcirc$ G		revolving axis
Rectangular prism $= \frac{l\, b\, d}{\square\ G}$	A		depth
	B		area*
	C breadth		
	D $\square$ G		
	A 1		length
	B area		content

EXAMPLES.

What is the content, in gallons, of a vessel in the shape of a square prism, 4 inches deep and 14½ inches along each of the sides?

C 3·03 gallons	4	
D 14·5	16·65	*Ans.* 3·03 gals.

Each side of a square pyramid is 46 inches, its perpendicular depth is 90 inches; what is its content in gallons?

C 30	229 gallons.	*Ans.*
D 16·65	46	

The depth of a cylinder is 20 inches, its diameter is 21½ inches; how many bushels will it contain?

C 3·275 bushels	20	
D 21·5	53·14	*Ans.* 3·275 bush.

The depth of a cone is 24 inches, its diameter 17; how many pounds of tallow will it hold?

C 60 lbs.	8	
D 17	6·2	*Ans.* 60 lbs.

What is the weight of a hollow globe of brass, the exterior diameter being 9 inches, and the interior 6 inches?

---

* The content of a solid whose length is unity is called an area, and finding such content is called averaging areas.

C 6		115	115
„ 4	34·		34
D 2·059	6	9	*Ans.* 81 lbs.

The fixed diameter of an oblate spheroid is 33 inches, its revolving diameter is 54 inches; how many bushels will it contain?

C 22	22·7 bushels.	*Ans.*
D 53·14	54	

A cistern is the shape of a rectangular prism, is 112·5 inches long, 41 inches broad, and 18 inches deep; how many gallons will it contain?

A 18		
B 2·66		
C	41	
D	16·65	
A 1	112·5	
B 2·6	300 gallons.	*Ans.*

Almost all the slide-rules now manufactured agree in having the four lines, A, B, C, D, upon one of their faces, the only exception being rules constructed solely for the purpose of one particular class of operations, an instance of which is afforded in the timber-cubing rule (p. 147). We proceed to notice a few of the best slide-rules.

The Routledge Slide-Rule has a joint in the middle, and is 24 inches long when opened out. One of the faces is graduated to inches, and also to a drawing scale; so that when looking at this face it has the appearance, and answers every purpose, of a common two-feet rule. One of the edges is divided to decimals of a foot, and the other to inches subdivided into tenths and twelfths. On closing the rule and turning it over we find one half of it forming a slide-rule 1 foot in length, with the lines A, B, C, D on it, the D line being numbered from 1 to 10; and on the other half are tables of gauge points, for square, cylinder, and globe, for regular polygons, for proportions of the circle, square, and triangle, and also one for pumping-engines. The old Coggleshall's rule was very similar to this, the only difference consisting in other tables holding the place of the table of gauge points, and the line D ranging from 4 to 40 instead of from 1 to 10.

Bayley's Slide-Rule is a very neat instrument, manufactured by Messrs. Elliott. It is 1 foot in length, having two grooves, one on the front, and one on the back; and as the slides for these grooves are each graduated on both sides, the instrument is equivalent to a rule with four slides. On one face are the A line above the groove and the D line below it, while the slide has on one face the B and C lines, as usual, and on the other the E line, on which the logarithmic line is repeated thrice, and the numbers on the divisions are the cubes of the numbers on the corresponding divisions of the D line, with which it works. On this slide is also a scale of equal parts marked Num, the whole length being divided into 1,000 equal parts, every two of which are graduated.

This line is used in conjunction with the D line; when placed evenly in the groove, the number of equal parts or thousandths of the entire length of the D line, reaching to any division of this line, represents the first three decimal places of the fractional part of the logarithm of the number marked against this division. The line is divided first into ten principal divisions, numbered 1, 2, 3, &c., indicating so many tenths; these are subdivided, each into ten secondary divisions, denoting hundredths; and each of these is again subdivided into five tertiary divisions, so that the half of one of these is a thousandth part of the whole line which represents unity. Laying the slide evenly in the groove, so that the first and last divisions on the line N coincide with the first and last divisions on the D line, the division of this line marked 2 will be found midway between the primary division on the N line, marked 3, and the first tertiary division beyond it; thus showing that the logarithm of 2 is ·301; and, in like manner, the other numbers on the D line will coincide with divisions above them, denoting the fractional portions of their logarithms. The integral part of any one of the logarithms is known from the consideration that it is one less than the number of integral places in the number of which it is the logarithm. These two lines, therefore, form a table of natural numbers on the D line, and of their logarithms on the line N, correct to the extent of three decimal places. A few logarithms to six places of decimals are recorded on one of the edges of the rule; viz., those that are required in the computation of compound interest, at ordinary rates, and of annuities and leases.

The other slide contains on both faces lines of sines and

C 6
„ 4
D 2·059

The fixed diam
revolving diamet
contain ?

C 22
D 53·14

A cistern is
inches long, 4
gallons will i

A 18
B 2
C
D
A
P

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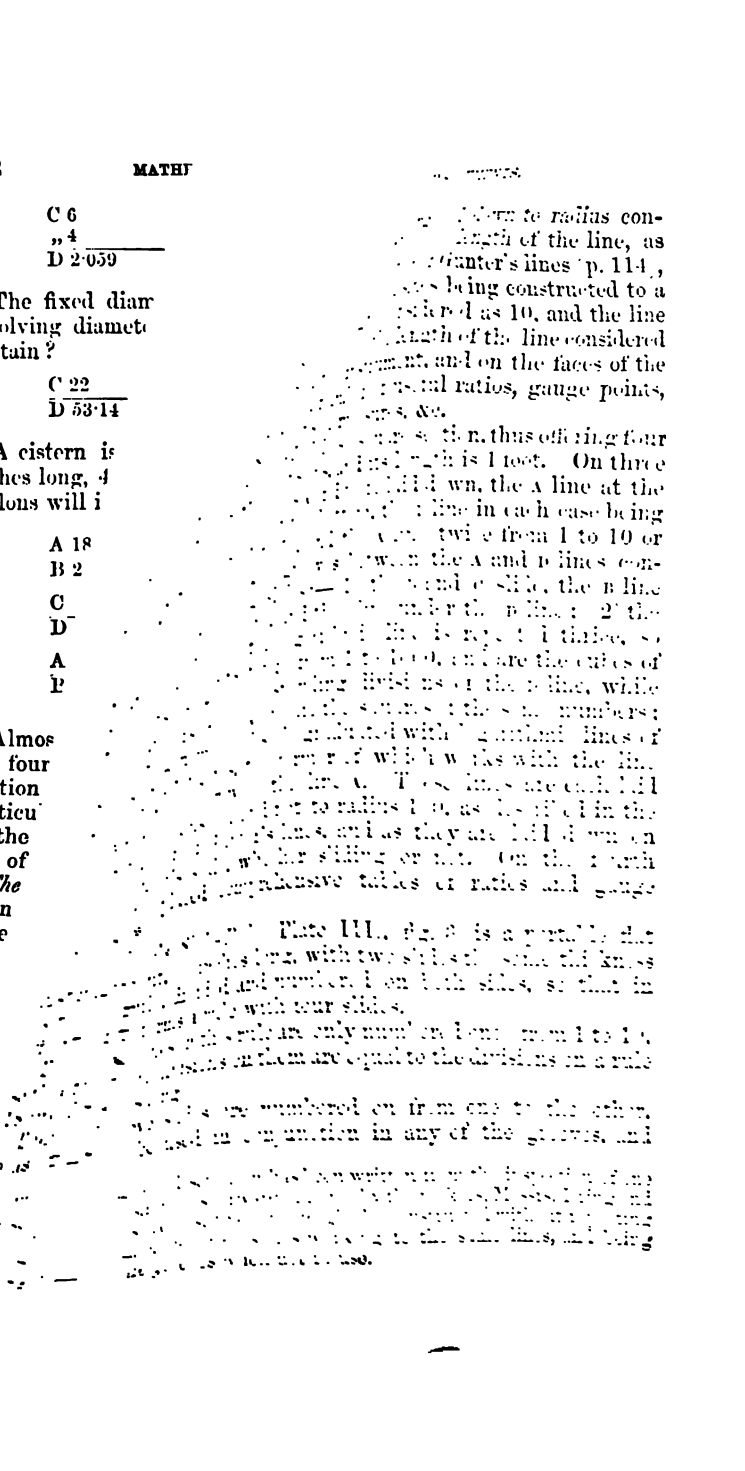


...radius con-
...length of the line, as
...Gunter's lines (p. 114),
...being constructed to a
...stated as 10, and the line
...length of the line considered
...ment, and on the faces of the
...rical ratios, gauge points,
...s, &c.
...ion, thus offering four
...inch is 1 foot. On three
...wn, the A line at the
...line in each case being
...twice from 1 to 10 or
...with the A and B lines con-
...and slide, the B line
...number the B line; 2 the
...is to 1, 3 to 1, and so on, the ratios of
...being indicated on the B line, while
...the same numbers;
...marked with decimal lines of
...with the line
...These lines are each 1·1
...to radius 1·0, as indicated in the
...lines, and as they are all drawn on
...without sliding or not. On the fourth
...comprehensive tables of ratios and gauge

Plate III., fig. 3 is a ...
...with two slides, one ...
...and number 1 on both sides, so that in
...with four slides.
...are only numbered from 1 to 1·...
...them are equal to the divisions on a rule
...
...numbered on from one to the other,
...used in any function in any of the gauges, and
...
...
...

Plate III.

Fig. 1.

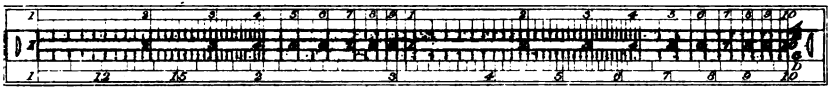


Fig. 2.

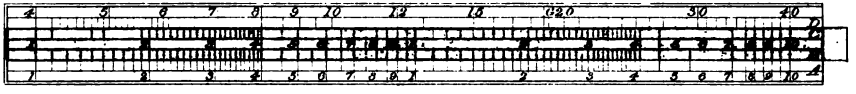
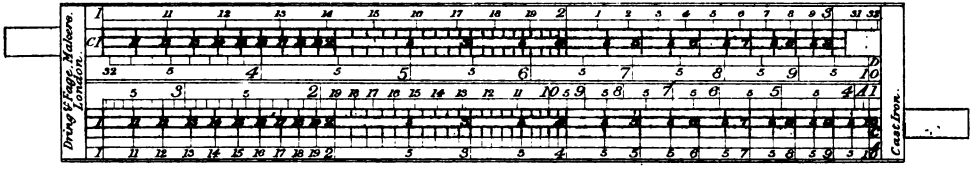



Fig. 3.

tangents, those on one face being laid down to radius considered as 100, and equal to the whole length of the line, as already described in the construction of Gunter's lines (p. 114), and on the other face the line of sines being constructed to a radius equal the whole length considered as 10, and the line of tangents to radius equal half the length of the line considered as 10. On the edges of the instrument, and on the faces of the grooves, are recorded a number of useful ratios, gauge points, logarithms, comparisons of measures, &c.

The Kentish Slide-Rule has a square section, thus offering four faces of similar dimensions, and its length is 1 foot. On three of these faces the lines A and D are laid down, the A line at the top, and the D line at the bottom, the D line in each case being numbered from 1 to 10, and the A line twice from 1 to 10 or from 1 to 100. The grooves between the A and D lines contain the following slides:—(1) the B and C slide, the B line being over the A line, and the C line under the D line; (2) the E slide, on which the logarithmic line is repeated thrice, so that the numbers range from 1 to 1000, and are the cubes of numbers on the corresponding divisions of the D line, while the numbers on the A line are the squares of the same numbers; (3) a trigonometrical slide graduated with logarithmic lines of sines and tangents, the former of which works with the line D, and the latter with the line A. These lines are each laid down to radius 10, and not to radius 100, as described in the construction of Gunter's lines, and as they are laid down on the Gunter's scale, whether sliding or not. On the fourth face are placed comprehensive tables of ratios and gauge points.*

Coulson's Slide-Rule (Plate III., fig. 3) is a portable flat instrument, 9½ inches long, with two slides the same thickness as the rule, divided and numbered on both sides, so that in effect it forms a rule with four slides.

The A lines on this rule are only numbered once from 1 to 10, so that the divisions on them are equal to the divisions on a rule 18 inches long.

The two slides are numbered on from one to the other, so as to be used in conjunction in any of the grooves, and

* The above description has been written from the inspection of one of these instruments forwarded to me by the makers, Messrs. Dring and Fage: it is manifest that they might be constructed without repeating the lines A, D, the three slides working to the same lines, and being held in spare grooves when not in use.

Plate III.

Fig. 1.

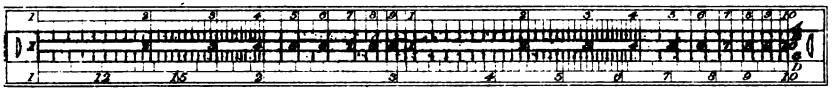


Fig. 2.

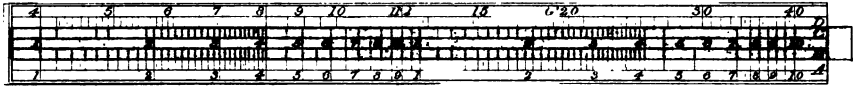
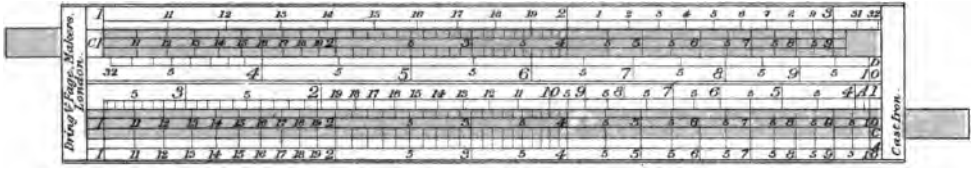


Fig. 3.

thus form a double line: by this means all the advantages of a rule of double the length, with double lines, are obtained.*

The line D, which is double the length of the rule, begins on the upper edge of the rule, and is numbered from left to right from 1 to 3·2, which is on the right end of the rule; the line is then continued below the groove, from 3·2 on the left to 10 on the right. This arrangement requires the numbers on the C line of the slide to be considered to belong to the first section of this line when used with the divisions above the slide, and to the second section when used with the divisions below the slide.

On the line D several gauge points are marked. At 1·128 is a brass pin, marked C C. In., signifying the cylindrical gauge point for cubic inches: this gauge point is also used for finding the content of a cylinder in cubic feet or cubic yards, when the length and diameter are given in feet or yards. In fact, in whatever dimensions the linear measurements may be given, this gauge point serves to determine the content in the same dimensions cubed. The gauge point and brass pin at 13·54, marked C C. Ft., signifies cylindrical gauge point for cubic feet: this gauge point is used for finding the content of a cylinder in cubic feet, when the length is given in feet, and the diameter in inches. The pin and gauge point at 42·53, marked C. Ft., is used for finding the content of a cylinder in cubic feet, when the length is given in feet, and the girth or circumference in inches. The gauge point and pin at 16·65, marked Im. G., is used for finding the content of a square vessel in imperial gallons. The gauge point and pin at 18·79, marked Im. G., is used for finding the content of a cylindrical vessel in imperial gallons. The pin and gauge point at 2·126, marked R. B. I., is used for finding the weight of a round bar of malleable iron in pounds, when the length and diameter are given in inches. The pin and gauge point at 2·21, marked R.C.I., is used for finding the weight of cylindrical cast iron in pounds, when the length and diameter are given in inches.

The gauge point and pin at 27, marked OX, is used for finding the neat dead weight of cattle, when the length and

* This is all that Mr. Coulson claims for it; but the simplification of the numeration on the rule, and the gain of a third section on the slide, when used with the D line, are advantages of far greater importance obtained by this form of construction.

girth are given in inches; and that at 27·6, marked Kyloes, is the gauge point for finding the neat dead weight of small Kyloes. The pin and gauge point at 47·1, marked M. B., is used for finding the content of a square vessel in malt bushels.

The lines marked "Cast Iron," on the same side of the rule, are used for finding the weight of that metal; the upper line, marked A I, signifies the A line *inverted*, which is done in such a manner that 3·836, the square divisor for cast iron, is directly opposite to 1 or 10 upon A; whence any three dimensions are multiplied together, and divided by the square divisor at one operation. The construction and use of these lines have been already explained (p. 128).

It has also been remarked, that the same result is obtained if the dimensions are used indiscriminately on the lines, only observing that the content is always found on C, opposite some one of the dimensions on A.

On the opposite side of the rule are lines marked "Cubic Yards," for finding the content of excavations, &c., in cubic yards, which are used in a similar manner to those for cast iron, the upper line A I being so arranged, that 27, the number of cubic feet in a cubic yard, is opposite to 1 or 10 upon A; the dimensions of course must be taken in feet and decimal parts.

For the convenience of ironfounders and others, to whom the lines marked "Cubic Yards" may not be useful, rules are also made with lines marked "Bar Iron," which are used for finding the weight of malleable iron bars, in a similar manner to those for cast iron.

On this side of the rule are also lines marked "Cubic Feet," which are used for finding the content of timber or other materials in cubic feet, the inverted line, marked A I, being so disposed that the square divisor, 144, is directly opposite to 1 or 10 upon A; the thickness and breadth, must be given in inches, and the length in feet, and these dimensions may, like those for cast iron, or cubic yards, be taken indiscriminately on any of the lines, always observing that the content must invariably be found on B, opposite one of the dimensions on A; to prevent confusion, however, it will be better for the learner to practise an invariable method, and I have, therefore, in the examples given on these lines, set the thickness *in inches* on B, to the breadth in inches in A I;* then, against the length *in*

* In setting the thickness on B to the breadth on A I, the *breadth* on B *is also set to* the *thickness* on A I at the same time.

feet on A, is the content in cubic feet on B. It must be carefully observed, that the figures and divisions *on all* the inverted lines, marked A I, *must be read from right to left.*

There is a brass pin and gauge point on the line A, at 2218·192, marked Im. B., for finding the content of a square or rectangular vessel in bushels at 1 inch deep; also a pin and gauge point at 277·274, marked Im. G., for finding the content of a square or rectangular vessel in imperial gallons at 1 inch deep; and a gauge point and pin at 353, marked C. Im. G., for finding the content of a circular or elliptical vessel, in imperial gallons at 1 inch deep. A gauge point and brass pin is placed at 3·1416 for finding the circumference of a circle, or the pitch of a wheel.

One of the edges of the rule is divided into inches and tenths, and numbered from the left to right with 1, 2, 3, 4, 5, 6, 7, 8, 9. Under this are two lines, the first marked "Spheroid," and the third line "Second Variety," and both are numbered, from the left to the right, with the figures 1, 2, 3, 4, 5, &c., and the spaces between each of these figures are divided into ten equal parts. These three lines are used for finding a mean diameter between the head and bung diameters of casks of the first and second varieties, which is performed in the following manner:—

Find the difference between the bung and head diameters on the first line, or line of inches, then against such difference, for each variety, is a number, which, being added to the head diameter, will give the mean diameter sought: hence the cask is reduced to a cylinder.

On the other edge of the rule are two A line radii, so disposed as to suit the finding of a mean diameter of a cask of the third variety, which is performed in the following manner:—

Find the difference between the bung and head diameters on the second or undermost line, then against that number is another number on the top line, which, if added to the head, will give a mean diameter; hence the cask will be, as in the preceding case, reduced to a cylinder.

For timber-measuring two slide-rules are used, one called the cubing rule, and the other the timber or timber-contenting rule.

The Cubing Rule.—This rule is three feet in length, and contains four lines, marked A, B, C, E. The E line is above, and the A line below, the groove; the lines B and C are on the

slide, the B line above the A line, with which it works, and the C line below the E line, with which it works. The A, C, and E lines are divided duodecimally, that is, into feet and inches; and the last, E, is inverted, so that the numbers taken on the three lines are multiplied together; and as the product of the three commencing numbers is placed against them on the commencement of the B line, the same is everywhere the case, and the rule gives the content at once in cubic feet.

On one side of the rule the E line commences at 5 inches, and runs back to twelve feet. The 1, 2, 3, and 4 inches are supplied by the 10, 20, 30, and 40 feet of the B line, which numbers have the 0 separated by a star, thus—1*0, 2*0, 3*0, 4*0, to signify that the 0 is to be rejected, and that they are to count only as 1, 2, 3, and 4 inches. In reality, however, though they are marked on the B line, they are the numbers on the C line; for the 20 of the B line cuts across the 1 foot 8 inches, that is the 20 inches, of the C line, on which, as it works to the E line, the two inches ought to be taken. The content in this case must, consequently, be reduced to one-tenth: for instance, if the content is found marked on the B line as 70, it is to be taken as 7; if 80, as 8; and so on.

The second side of the rule is a continuation of the first, the one being for small numbers, the other for large.

When none of the dimensions are under 5 inches, they are taken upon the lines in the order denoted by the word E C A B; when one is under 5 inches, and therefore marked with a star, by the word E B A B. Consequently, when taken in the order E C A B, the figures on the rule show the correct content; when in the order E B A B, one-tenth of the content shown by the rule is to be taken.

The B line is divided decimally, giving the solidity in cubic feet and tenths.

EXAMPLES.

A pile of deals is 20 feet 7 inches wide, 4 feet 7 inches high, and 14 feet long: required its content.

20 ft. 7 in. E : 4 ft. 7 in. C : 14 ft. A : 1320 cub. ft. B.

E 20 ft. 7 in.	
C 4 ft. 7 in.	
B	1320 cub. ft.
A	14 ft.

A deal is 14 feet long, 2 feet 3 inches wide, and 3 inches thick: required the content.

2 ft. 3 in. E : 3 in. B : 14 ft. A : 7·88 cub. ft. B.

E	2 ft. 3 in.	
C	2 ft. 6 in.	
B	3*0	78·8 cub. ft.
A		14

The Timber-contenting Rule.—This is usually 2 feet long. One side contains four lines, A, B, C, and E, the last of which is inverted, and so graduated that 144 falls opposite the commencement of the slide; consequently it divides the product by 144 (p. 129), and reduces square inches to square feet. Therefore, by taking the length of a piece of timber in feet, and the thickness and width in inches, it gives the content in cubic feet. The dimensions are taken, as in the cubing rule, in the order of the letters E C A B, the last or B line exhibiting the content. The A, C, and E lines are divided into fourths, the B line decimally.

The other side of the rule contains the usual A, B, C, and D lines; the last of which, termed the girt line, or more properly the quarter-girt line, is made to commence at 4 and run on to 40. On this face of the rule the following points are marked with brass pins:—the division on the A line at 12, for reducing linear inches to feet; the square-gauge point on the D line at $\frac{\downarrow}{12}$; the circular, hexdecagonal, and octagonal quarter-girt gauge points between the 10 and 11, marked $\overset{\text{O}}{\downarrow}\ \overset{16}{\downarrow}\ \overset{8}{\downarrow}$; and the octagonal, hexdecagonal, and circular diameter gauge points between the 13 and 14, marked $\overset{8}{\downarrow}\ \overset{16}{\downarrow}\ \overset{\text{O}}{\downarrow}$. The O denotes the gauge points for round timber; the 16, for hexdecagonal or sixteen-sided timber; and the 8, for octagonal or eight-sided timber.

The words girt and diameter explain themselves; the former denoting the measure round, the latter across. As applied to octagonal and hexdecagonal timber, by diameter is to be understood the perpendicular distance between opposite sides, in contradistinction to diagonal, which is the distance between opposite angles; or as applied to polygons in general, the term diameter is applied to the diameter of

the inscribed circle, the term diagonal to the diameter of the circumscribed circle. It is to be borne in mind that with the diameter-gauge points the *whole* of the diameter is taken; with the girt or more properly quarter-girt points only *one-fourth* of the girt is taken. We proceed to explain fully the meaning and use of these gauge points.

In a square, the diameter, side, and quarter-girt are equal, and, if they each measure 1 inch, 144 such squares make a foot. Consequently, the square divisor is 144, to be taken on A, and 12, the square root of 144, is the square-gauge point to be taken on D, to reduce to square feet the area of a square, the side of which is given in inches.

If the diameter of a regular octagon be 1 inch, then 173·82 such octagons make a square foot. If, then, the diameter of a regular octagon be taken in inches, 173·82 is the divisor, to be taken on A, and its square root, 13·18, is the diameter-gauge point, to be taken on D, to reduce the area of the octagon to square feet.

If the perimeter of a regular octagon be 4 inches, so that the quarter-girt is 1 inch, 119·29 such octagons make a square foot: consequently 119·29 is the quarter-girt divisor, and its square root, 10·92, the quarter-girt gauge point, for this figure.

If the diameter of a regular hexdecagon be 1 inch, then 180·98 such hexdecagons make a square foot; and if the perimeter of a regular hexdecagon be 4 inches, then 114·57 such hexdecagons make a square foot. Consequently, 180·98 and 114·57 are the diameter and quarter-girt divisors; and their square roots, 13·45 and 10·7, are the gauge points for this figure.

If the diameter of a circle be 1 inch, then 183·35 such circles make a square foot, and if the circumference be 4 inches, then 113·1 such circles make a square foot. Consequently, 183·35 and 113·1 are the diameter and quarter-girt divisors, and their square roots, 13·54 and 10·63, are the gauge points for the circular area to reduce it to square feet.

The squares of the diameters or quarter-girts in inches, and the divisors being taken on A, their quotients on B will give the sectional areas of a piece of timber or other material in square feet; and the same result will be obtained if the diameters or quarter-girts in inches, and the gauge points be taken on D, and their quotients on C.

If, then, the diameters or quarter-girts be taken in inches, and the lengths in feet, the products of the lengths and sectional areas will give the contents in cubic feet.

EXAMPLES WITH TIMBER RULE.

A plank is 36 feet long, $9\frac{3}{4}$ inches broad, and $4\frac{1}{2}$ inches thick: required its content.

E $9\frac{3}{4}$		
C $4\frac{1}{2}$		
B	10·97 cub. ft.	*Ans.*
A	36	

A piece of timber is $63\frac{1}{2}$ feet long, and $17\frac{1}{2}$ inches square: required its content.

C $63\frac{1}{2}$	135 cub. ft.	*Ans.*
D 12	$17\frac{1}{2}$	

An octagonal mast is $72\frac{1}{4}$ feet long, and $21\frac{3}{4}$ mean diameter: required its content.

C $72\frac{1}{4}$	196 cub. ft.	*Ans.*
D 8	$21\frac{3}{4}$	
diameter		

A hexdecagonal mast is $72\frac{1}{2}$ feet long, and 69 inches round in the middle: required the content.

C $72\frac{1}{2}$	188 cub. ft.	*Ans.*
D 16	$17\frac{1}{4}$	
girt		

A round mast is 85 feet long, and $23\frac{3}{4}$ inches mean diameter: required the content.

C 85	261 cub. ft.	*Ans.*
D o	$23\frac{3}{4}$	
diameter		

MEASURING INSTRUMENTS—TIMBER MEASURERS.

Having now discussed rather fully those instruments which are used for computations based upon given dimensions, we proceed to describe some of the best instruments for taking dimensions—first describing those used by timber-measurers for taking the dimensions required for

the computations to be performed with the cubing and timber rules just described. These are the hull callipers, bow callipers, graduated steel bar, plank rule, girt tape, timber rod, and scribing-iron.

The *Hull Callipers* are used for taking the thickness of square timber, and consist of a steel stock, graduated upon both sides and the edge in inches and quarters, and with the end bent at right angles, so as to form a fixed arm and claw. To ascertain the thickness of a log of timber, open the arms of the callipers, and place the fixed claw against one side, then slide the other arm towards it until stopped by contact with the log; the required dimensions, in inches and quarters, upon the steel stock are now shown against the lower edge of the sliding arm. Care must be taken that neither is placed in any hole or crack in the timber, or a considerable error in the estimated content will be the result.

The callipers should be tested occasionally, to see that the indications of the graduated stock agree with the distance between the claws. They are usually made in sizes from 18 to 48 inches; the 18-inch callipers commence at one inch, the larger sizes are not graduated below 4 inches.

The Bow Callipers are used for taking the diameters of large, round, and irregular timber. They are to be placed so that the points touch at the required parts; the points are then to be transferred to the graduated steel bar which will give the distance in inches and quarters.

The Steel Bar is used in conjunction with the bow callipers, and is graduated on each side with inches and quarters, from 3 to 33 inches, so as to indicate the dimensions taken. It is usually carried in the left hand; and, being shaped like a crowbar, is useful for shifting the logs, so as to place them in the best position for measuring.

The Plank Rule is a sliding boxwood calliper, furnished with steel tips, and is used for ascertaining the width and thickness of planks. The graduations upon it are in inches and quarters, from $\frac{1}{2}$ inch to 24 inches.

The Girt Tape is a broad strong tape, marked on one side in plain inches, after the usual manner, so as to show the perimeter, or girt, of a piece of timber; on the other side every inch counts but as a quarter, so that when the tape is passed round the log under measurement, the quarter-girt is shown at once where the brass ring intersects the tape. This

is a far more accurate and expeditious mode than the old plan of taking the girt with a piece of string, and then measuring the latter with a rule.

The Timber Rods are painted deal rods, with a hook at one end, for ascertaining the length of timber. They are made in different lengths, from 5 to 20 feet, and are marked with feet and quarters, or, for more accurate measurement, with feet and inches. When they are of a greater length than 10 feet, it is advisable to have them jointed.

The Scribing Iron is for marking the content: it is made of two sizes—large for the hand, and small for the pocket.

Instruments similar to those just described are manifestly adapted to the measurement in any direction of bodies of a great variety of forms, where an approximate estimate of their dimensions is all that is required. We now proceed to describe a few instruments which are adapted to measure distances and dimensions with the greatest amount of accuracy that is practically available.

THE SPHEROMETER.

This is a delicate instrument for measuring the diameter of bullets and spherical bodies. It consists of a

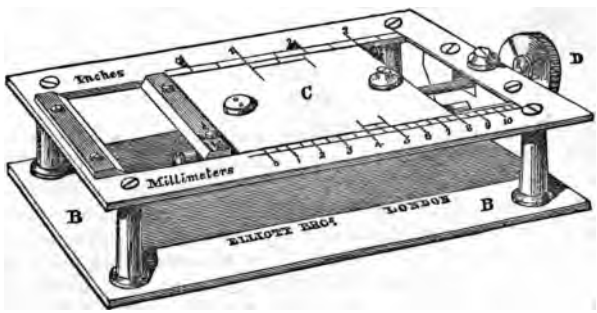


Fig. 1.

frame supported on pillars rising from a stand, B B. In the frame works an accurately fitting slide, C, to which a slow motion is given by the screw D. On the inner edges of the frame are two scales—that on one side being divided into $\frac{1}{10}$ths of an inch, and that on the other into millimètres; while

on the edges of the slide are two verniers—that on one side subdividing the divisions into 20, so as to read to $\frac{1}{1000}$th of an inch, and that on the other subdividing the millimètres into 10. In using it, the bullet is passed between the bevelled edges shown at the ends of the frame and of the slide.

THE EXTENSOMETER.

This is an instrument for measuring the extension of bars or rods, produced by given strains. It consists of two clamps, A and B, to one of which, A, is attached a frame, C C, and to the other a slide, D D, working accurately in that frame. The clamps, being placed upon the rod or bar to be experimented upon, are held in their place by turning the milled-headed screws S S. The rod being then subjected to a strain, which is

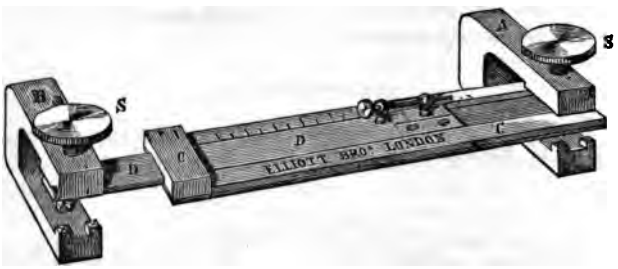


Fig. 2.

accurately measured by a balance composed of a system of levers, the points of the screws retain the positions to which they have been turned down upon the bar, and the distance to which the slide is drawn out shows the amount of extension of the rod in a length equal to the distance between the original points of the screws. The measurements are read from a scale on the frame divided to $\frac{1}{50}$th of an inch, by means of a vernier subdividing each division of the scale into 20, and thus giving the reading to the $\frac{1}{1000}$th of an inch.

GERMAN-SILVER WIRE GAUGE.

In this beautiful little instrument, accurate minute measurements are arrived at by a process differing from those just described. It consists of a claw, A B C, having its arms A and

C at right angles to its stock, B. The arms A and B terminate in cylindrical heads, pierced by female screws having their axes in the same straight line, and through these pass two male screws having their extremities accurately ground, so that when brought into contact no light can penetrate between them. The cylindrical head is prolonged and graduated on its surface to $\frac{1}{50}$th of an inch, which is the distance between the threads of the screw, and the screw working through this cylinder is attached to a milled head; and to this head is also attached a hollow cylinder, F, concentric with the screw and cylinder in which it works, and just working over the surface of this cylinder. The extremity of the cylinder F is bevelled, and graduated into 20 equal parts, so that the passage of one of those parts past an index on the cylinder E indicates a $\frac{1}{20}$th part of a turn of the screw, and therefore a motion of the extremity of this screw through a distance of $\frac{1}{1000}$th of an inch. The screw in the cylinder D is adjusted by the hand so that the graduations on the cylinders E and F shall both read zero, when the two screws are brought into contact; and, consequently, when a wire or any other substance, the thickness of which it is desired to measure, is placed between the screws, and the milled head turned until it is held firmly between them, without being compressed, the readings in the cylinders E and F give the required dimension to the $\frac{1}{1000}$th part of an inch, those on E recording the number of turns, and those on F the parts of a turn, in the distance between the extremities of the screws.

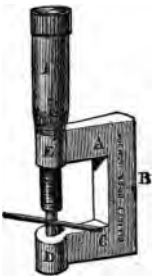


Fig. 3.

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